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A Reveiw of Critical Human Factors Issues for Aviation Team Training

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ABSTRACT

This report reviews literature relevant to team training in complex environments. While technological developments allow for the training of higher-order cognitive skills in complex simulated environments, in the absence of sound learning methodologies, training systems may not fully achieve their desired objectives. There are relatively few attempts in the literature that focus on how best to use technology to support effective training, and little research effort has involved the use of technology in the development of effective training programs for teams rather than individuals. The effectiveness of team training systems, and specifically, the measures of team outcomes and team processes that could be used to measure team performance in distributed training, are also reviewed. Some areas for future research relevant to distributed team training are identified.

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A Review of Critical Human Factors Issues for Aviation Team Training

Executive Summary

This report was prepared for Task Number AIR 01/248 Distributed Mission Training Systems for RAAF. The Distributed Mission Training (DMT) task at DSTO is initially focussing on RAAF F/A-18 operational requirements involving Aircrew, Regional Operator Centre Command Teams, and Air Defence Ground Environment Tactical Data System Operators.

This report reviews literature relevant to team training in complex environments. The first section reviews the psychological literature concerning cognitive processes for teams, with a focus on shared situation awareness, mental models, and team decision-making. The main aim of this section is to highlight some of the higher-order processes that are believed to be highly developed in effective teams.

The second section reviews the more prominent and relevant forms of team training and instructional strategies. While the Event-Based Approach to Training teams in complex high technology environments has been widely used in the military domain, there may also be a role for other forms of team training, such as team coordination training and cross training, in distributed team training. The extent to which these other forms of team training might be involved in distributed training would depend largely on the extent to which the critical team processes are adequately covered in the EBAT approach.

The final section of the report considers the measurement of team performance. Team outcome measures assess whether the team as a whole was successful in achieving its objectives, whereas team process measures are required to determine how the team went about achieving its objectives. The significant majority of this section concerns measures of team processes. Measures of the core dimensions of teamwork identify the degree to which teamwork behaviours are displayed by the team. These measurement tools can contain generic teamwork behaviours, in the case of the Teamwork Observation Measure, or identified teamwork behaviours that are specific to a given scenario for a given team, in the case of the Targeted Acceptable Responses to Generated Events or Tasks approach. While being more labour intensive, this latter approach offers the greatest potential for measurement of team processes for Distributed Mission Training. The measures of shared mental models and situation awareness are very much aimed at the individual level and collated to represent team values, hence further effort should be directed towards exploring measures where the team is the unit of analysis.

While there have been many studies that have examined different aspects of team training and performance, very little is known about team processes and performance for

distributed teams. Some future areas of research are identified that aim to increase our understanding and measurement of distributed team processes and ultimately enhance the effectiveness of Distributed Mission Training.

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Michael Lenné is a Research Scientist specialising in Human Factors within Air Operations Division. He has a B.Sc. (Hons) in Psychology and a Ph.D. in Human Factors Psychology from Monash University. He has extensive experience in the use of simulation to measure the influence of factors such as operator experience, workload, fatigue, and drugs on performance. His work currently includes exploring techniques for optimising the effectiveness of team training.

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Glossary

AAR	After Action Review
AAW	Anti-Air Warfare
ACAQ	Aircrew Coordination Attitudes Questionnaire
ACT	Adaptive Component of Thought
ATOM	Anti-Air Teamwork Observation Measure
AWACS	Airborne Warning and Control System
CAS	Close Air Support
CDQ	Coordination Demand Questionnaire
CIC	Combat Information Centre
CMAQ	Cockpit Management Attitudes Questionnaire
CRM	Crew Resource Management
CTA	Cognitive Task Analysis
CDM	Critical Decision Method
CTC	Combat Training Centre
CWA	Cognitive Work Analysis
DMT	Distributed Mission Training
EBAT	Event Based Approach to Training
HTA	Hierarchical Task Analysis
ISD	Instructional Systems Design
LOFT	Line of Flight Training
MSEL	Master Scenario Event List
NDM	Naturalistic Decision Making
RPD	Recognition Primed Decision Making
SA	Situation Awareness
SAT	Surface Attack Tactics
SAGAT	Situation Awareness Global Assessment Technique
SALIANT	Situation Awareness Linked Indicators Adapted to Novel Tasks
SME	Subject Matter Expert
TACT	Team Adaptation and Coordination Training
TADMUS	Tactical Decision Making Under Stress
TARGETS	Targeted Acceptable Responses to Generated Events or Tasks
TCR	Transfer Cost Ratio
TER	Transfer Effectiveness Ratio
TDT	Team Dimensional Training
TOM	Teamwork Observation Measure
TRS	Teamwork Rating Scale
VE	Virtual Environment
WDA	Work Domain Analysis

1. Introduction

This report was written for Task Number AIR 01/248 Distributed Mission Training (DMT) Systems for RAAF. The DMT task at DSTO is initially focussing on RAAF F/A-18 operational requirements involving Aircrew, Regional Operator Centre Command Teams, and Air Defence Ground Environment Tactical Data System Operators.

This report reviews literature relevant to team training in complex environments. Technological developments allow for the training of higher-order cognitive skills associated with human performance in complex simulated environments. Technology alone however does not ensure that effective training will occur. In the absence of sound learning methodologies, training systems may not fully achieve their desired objectives. There are relatively few attempts in the literature that focus on how best to use technology to support effective training. This latter point is a critical issue and is the major focus of this review. Furthermore, very little research effort has involved the use of technology in the development of effective training programs for teams rather than individuals. Another key focus area of this report is the effectiveness of training systems, and specifically, exploring the measures of team outcomes and team processes that could be used to measure team performance in distributed training. In essence the core question that is being addressed in this review is this - How should technology best be used to provide an efficient and effective environment for distributed team training?

Before commencing with the review of the literature it is instructive to explore the concept of DMT in the Australian context. There are some objectives of DMT that become apparent when considering RAAF sources of information. Two broad objectives are to develop an aircrew training system that accommodates mission rehearsal, and to develop an aircrew training system that provides effective team training and learning of cognitive skills involved in complex air operations.

The first objective relating to mission rehearsal encompasses the belief that forces should "train the way we fight' (Layton, 2000). Training needs to prepare the forces for combat by simulating as closely as possible the combat environment in which they are likely to find themselves. Exercising and training only one component of the force, or training each part separate from the others, results in no opportunity for exercising the interactions and building the cohesion that will be essential for effective operations.

The second objective relating to effective team training really emphasises the need for effective team training of cognitive rather than motor skills. The DMT system purpose is to enable defence personnel to learn and practice the intellectual skills involved in complex air operations such as rapidly analysing incoming data, deducing threat intentions, coordinating action, and optimising system employment. DMT will not provide the required motor skill training needed to varying degrees by all aircrew and ground crew, but rather has the primary goal of team learning (Layton, 2000).

It seems that DMT has potential benefits that relate specifically to crew performance and other benefits that relate to operational/organisational performance. Of greatest interest to human factors researchers are the benefits that relate more specifically to crew performance as improving crew performance seems to be a logical primary goal of DMT, and it is what training programs aim to achieve and what human factors researchers can measure and evaluate in an experimental setting.

There are a number of potential benefits from DMT that relate to crew performance:

1. Firstly, improved opportunities for team training and review of performance and tactical doctrine - Teamwork, communication and coordination training can be undertaken in a manner not possible with live exercises as events can be frozen and restarted to ensure learning points are understood. DMT can be used for exploring situations that have occurred in exercises for further evaluation and education adding to the team learning value.
2. Crew preparedness - Crews should be better prepared for the unexpected as they would have experienced a wider range of possible combat situations than is possible during normal training (Layton, 2000).
3. Maintenance of combat proficiency - Potential for gaining and maintaining proficiency levels without increasing flying hours.
4. Enhanced reserve aircrew training - DMT may allow the maintaining of reserve crew at a useful currency status (Layton, 2000).

Of course there are other benefits from DMT that do not specifically relate to crew performance such as:

1. More efficient use of (limited) actual flying hours - flying hours could be used more for refining intellectual skills rather than for their initial learning.
2. Trialing of new equipment – the research and development that DSTO could undertake to support air operations would be enhanced by being able to analyse DMT missions, evaluate proposed tactical changes, and trial new equipment options (Layton, 2000).

It is important to note that the limited documentation available concerning DMT emphasises issues such as team training, intellectual skills, team learning, and transfer of training. The DSTO approach to DMT should consider that the training system to be developed should ideally foster both efficient team training (i.e., team learning of cognitive skills) and maintenance and attainment of combat proficiency and readiness via mission rehearsal.

Having briefly outlined what a distributed training system is aiming to achieve, the report following reviews literature that is relevant to the attainment of these goals. Primarily, this literature concerns issues such as the identification of key competencies, instructional strategies, and measures of performance as they relate to team functioning.

To embark on a review of the training and team performance literature is indeed a sizeable task. In an attempt to tie together the areas of training theory and practice, it is worthwhile to draw upon a conceptual framework for organising the training research proposed by Cannon-Bowers et al. (1991). This framework aims to clarify the relationship between various areas of training theory and between theory and practice. It also incorporates three important questions relevant to training research: (1) What should be trained (what are the knowledge, skills, and attitudes that must be trained)? (2) How should training be designed? (3) Is training effective, and why? There are conceptual and theoretical developments, as well as training techniques, associated with each of these questions. In the interests of clarity and providing a link between areas of research and practice, the organisation of this review of research relevant to team training will follow the framework described by Cannon-Bowers et al. (1991).

2. Competencies and cognitive processes for team training

It is important to reiterate that, at this point in time, DMT does not focus on manual control skills, and as such, the majority of this section focuses on higher-order cognitive processes. There is a sizeable body of literature on the required competencies that should form the basis of team training. These competencies will be the initial focus of this section, but then discussions will move to higher-level team 'processes' and associated research.

It should also be stated that virtually none of the team training literature pertains to distributed teams, that is, when team members are at physically different locations. While there are certainly bound to be some differences in the functioning of distributed versus co-located teams, it is instructive to consider what is already known about how co-located teams function before considering the functioning of distributed teams.

2.1 Competencies that affect teamwork

Published literature over the last decade describes three major components, that when combined, define teamwork. These competencies are cognitions (knowledge-based competencies), behaviour (skill-based competencies) and attitudes (attitude-based competencies) (Salas & Cannon-Bowers, 2000).

It is worth mentioning here some of the basic elements that make up a team. Indeed there are a number of characteristics that have been established in the literature that define the characteristics of teams. Some of these are that: team members have meaningful task interdependencies; team members hold shared and valued objectives/goals; team members are hierarchically organised; team members hold specialised roles and responsibilities; team members use multiple information sources; team members possess adaptive mechanisms; and team members perform through intensive communication processes (Salas & Cannon-Bowers, 2000).

2.1.1 Cognitions

Teamwork has a cognitively-based element in that knowledge is required in order to perform the team tasks. It has been suggested that team members must possess compatible mental models (knowledge structures) of their team-mates' roles, the tasks, and the situations that the team encounters, in order to be effective (Salas & Cannon-Bowers, 2000). These knowledge structures create expectations and allow for individuals to make predictions concerning how to perform during both routine and novel situations (Cannon-Bowers, Salas, & Converse, 1993).

Research also suggests that team members should possess knowledge about the purpose and objectives of their mission, and the norms that are expected to be followed. They must also understand the importance of teamwork, their individual roles, and the

responsibilities of their team-mates (Cannon-Bowers et al., 1993; Cannon-Bowers, Tannenbaum, Salas, & Volpe, 1995).

Cue strategy associations are a key knowledge-based strategy (Cannon-Bowers et al., 1993; Cannon-Bowers et al., 1995). That is, team members need to be able to make an association between a set of cues and the actions that need to be undertaken – the cues in the environment should trigger team members to behave in a particular way. It is this type of knowledge that allows team members to perform frequently without the need for overt communication (Salas & Cannon-Bowers, 2000).

The concepts of knowledge structures, mental models, and other cognitive processes important for effective team functioning are pursued in detail in a later section (section 2.2). The aim here is merely to provide an overview of the different types of competencies that contribute to teamwork.

2.1.2 Behaviour

Team members require the skills to allow them to perform and act in a timely and accurate fashion. As such there has been considerable research directed toward uncovering consistent behaviours of effective teams. There are actions that team members can take that have been shown to influence teamwork. For example, these include: performance monitoring; performing self-correction; providing tasks and motivational reinforcement; using closed-loop communication; adapting to unpredictable situations; being assertive, and; employing implicit or explicit coordination of activities. According to Salas & Cannon-Bowers (2000) the skill-based competencies that are associated with effective teamwork include adaptability, mutual performance monitoring, team leadership, communication, assertiveness, and conflict resolution.

2.1.3 Attitudes

Attitudes about the task and other team members will have a significant impact on teamwork. Willingness to remain in the group, team morale, beliefs of the importance of teamwork, and motivation of the team members all influence the effectiveness of teamwork. Collective orientation, being the disposition to receive and value inputs from others, and self-efficacy, are other critical factors in facilitating teamwork.

Teamwork is the seamless integration of related knowledge, skills, and attitudes that team members use to optimise performance. It is important to have an understanding of these knowledge, skills, and attitudes, as they are the target of team training, which of course aims to improve effective teamwork (Salas & Cannon-Bowers, 2000).

Table 1 below provides some generic examples of cognitive, behavioural, and attitudinal competencies for team training.

Table 1. Examples of Cognitive, Behavioural, and Attitudinal competencies for team training (adapted from Salas & Cannon-Bowers, 2000).

Nature of team competency	Description of team competency	Knowledge	Skills	Attitudes
Context-driven	Task specific, team specific	• Cue strategy associations • Task-specific team-mate characteristics • Team-specific role responsibilities • Shared mental models • Team mission, objectives, norms, resources	• Task organisation • Mutual performance monitoring • Shared problem-model development • Flexibility • Compensatory behaviour • Information exchange • Dynamic reallocation of functions • Mission analysis • Task structuring • Task interaction • Motivation of others	• Team orientation (morale) • Collective efficacy • Shared vision
Team contingent	Task generic, team specific	• Team mate characteristics • Team mission, objectives, norms, resources • Relationship to larger organisation	• Conflict resolution • Motiva tion of others • Information exchange • Intra-team feedback • Compensatory behaviour • Assertiveness • Planning • Flexibility • Morale building • Cooperation	• Team cohesion • Interpersonal relations • Mutual trust
Task contingent	Task specific, team generic	• Task-specific role responsibilities • Task sequencing • Team role-interaction patterns • Procedures for task accomplishment • Accurate task models • Accurate problem models • Boundary-spanning role • Cue-strategy associations	• Task structuring • Mission analysis • Mutual performance monitoring • Compensatory behaviour • Information exchange • Intra-team feedback • Assertiveness • Flexibility • Planning • Task interaction • Situational awareness	• Task-specific teamwork attitudes
Transportable	Task generic, team generic	• Team work skills	• Morale building • Conflict resolution • Information exchange • Task motivation • Cooperation • Consulting with others • assertiveness	• Collective orientation • Belief in the importance of teamwork

2.1.4 Principles, Guidelines, and Specifications

Training should be based on solid principles and knowledge of human learning, and trainers should rely on theoretically driven and empirically validated instructional principles to drive the instructional design process. Salas and Cannon-Bowers (2000) present some categories of principles for teamwork. These categories are general, adaptability-related, communication-related, performance monitoring/feedback-related, interpersonal relations, and coordination/cooperation-related principles. More specifically, those authors also put forward a number of general principles that relate only to the design and delivery of team-training programs. Salas and Cannon-Bowers (2000) state that these principles are supported by evidence of their utility and effectiveness. Some of these principles of team training are:

- Team training must facilitate information presentation, demonstration of teamwork behaviours, practice, and feedback;
- Teams must be provided with immediate feedback about their performance during training;
- Team members who require transportable competencies (i.e., generic competencies applicable across a range of situations) must receive training at the individual level;
- Transfer will be facilitated when individuals receive training directed at individual skills before receiving training at the team level;
- Transfer will be facilitated when the transition from individual to team training is based on the formation of shared knowledge and understanding of the team and its tasks; and
- Teams that need to develop team-specific competencies from either team-contingent or context-driven categories must receive training that includes feedback that facilitates the formation of shared or common expectations for task performance.

Some guidelines for team training are also put forward. These guidelines translate the principles into practice, and thus aid in the design and development of team-training programs (e.g., exercise the team with a variety of novel situations to build an adaptive repertoire). These guidelines have been developed to provide some insight into the selection of appropriate competencies for team training (i.e., not all competencies will be of similar importance across different teams and tasks). Some competencies may be specific to a particular task or team, or generic in that they may apply across teams and tasks. In considering the competencies that need to be trained, it is important to consider the stability of both team members and the tasks performed over time. The nature of team and task stability will align the competencies required to one of the four categories (Cannon-Bowers et al., 1995). Specifications are more precise statements about how team training should be designed, and state specifically what to do and when to do it.

2.1.5 Summary

The preceding four sections briefly discuss the three major generic types of competency thought to be required for effective team functioning, and some principles and guidelines to promote their implementation in training programs. While the principles and guidelines are intuitive and of general interest value, they are descriptive only and do not provide any solid guidance relating to how to develop or structure a team-training program. Nonetheless even a brief examination of the team training literature yields many references discussing team competencies, principles, and guidelines.

While there have been many competencies identified in the team training literature, there are some that appear to be more critical than others. In reviewing the team work literature, Dickinson et al. (1992, as cited in Dickinson & McIntyre, 1997) identified and defined seven core components of teamwork as part of a teamwork model. These core components are as follows:

1) Communication is a major component of teamwork processes, and is a mechanism that links the other components of teamwork.
2) Team orientation refers to the attitudes that team members have toward one another, the team task, and the team leadership, as well as including team cohesion.
3) Team leadership includes the structure provided by the designated leaders as well as other team members. It also emphasises the importance and planning to support team member functions.
4) Monitoring and awareness of the activities and performance of other team members is also an important team process. It implies that individual team members have a good understanding of the tasks of other team members.
5) Feedback is critical in that giving and receiving of feedback among team members helps teams to adapt and learn from their performance.
6) Backup behaviour concerns assisting other team members to perform their tasks, which assumes a degree of task interchangeability among team members, and willingness to provide and seek assistance.
7) Coordination reflects an organised execution of team tasks such that team members respond as a function of the behaviour of others. Coordinated team performance is dependent upon effective teamwork dimensions such as communication, monitoring, and backup.

The following section addresses some of the cognitive team processes that underpin these dimensions of teamwork.

2.2 Cognitive Processes for Teams

Teams process information, make decisions, solve problems, and make plans. Thorndike & Klein (1989, as cited in Klein 2000) suggested that teams can be considered as an intelligent entity, and hence it is possible to try to identify the key cognitive processes required by the tasks that depend on teamwork. The cognitive processes important for teamwork defined

and discussed by Klein (2000) are: control of attention; shared situation awareness; shared mental models; application of strategies and heuristics to make decisions, solve problems, and plan, and; metacognition. These processes are discussed in more detail in the following paragraphs.

2.2.1 Control of attention

The control of attention is the first of the five cognitive processes. In a team context it refers to the way that information is managed. Skilled teams learn effective information management – specifically they distribute critical information, filter irrelevant messages, allocate attention to important functions, and seek missing information. It also encompasses a team's working memory, being the way it uses limited resources to process inputs in parallel (Klein, 2000). Others have suggested that information management should be regarded as being one requirement of resource management, which also encompasses management of cognitive work, communication, and action (Orasanu, 1993). Nonetheless, information management becomes more critical as teams become distributed (Klein, 2000).

2.2.2 Shared Situation Awareness

Team situation awareness (SA) has been described as being one of two types of team knowledge, and is encompassed in the team situation model (Cooke et al., 2000). The second form of team knowledge, encompassed by the shared mental model, is discussed in the following section.

The extent to which team members have the same interpretation of events is referred to as shared SA. SA involves interpreting situation cues to recognise that a problem exists which may require a decision or action – it is not enough to simply notice the presence of cues as their significance must also be appreciated (Orasanu, 1993). As with the majority of constructs, shared SA is more important in dynamic and complex environments where there is greater potential for team members to develop differing interpretations of the situation which can create significant problems. Providing all team members with all information is also not a solution as this will undoubtedly just overload the team members unnecessarily. Thought should also be given to whether it might actually be an advantage for individuals to have slightly different interpretations of current events. That is, teams may actually benefit from team members having differing interpretations of the situation. This might hold in situations were uncertainty is high, so even if the team leader is mistaken in his/her interpretation there would be a greater chance of other team members recognising the mistake, and depending on the efficiency of information management, rectifying the situation accordingly (Schraagen et al., 2000).

Before discussing team SA further, it is important to consider theoretical perspectives of individual SA so as to provide a base for analysing team SA.

2.2.2.1 *A definition and model of situational awareness*

There has been much research and discussion about the concept of SA in the past decade. SA is founded on the assumption that the first critical step for successful task performance is an evaluation of the 'situation' (Wickens, Gordon, & Liu, 1998). The concept of SA and its importance in operator performance has developed to such a point that, for example, in military aviation, SA is evaluated on nearly every training event because it is seen to be critical to mission success (Oser, 2000).

The definition of SA has also evolved over the last ten years. According to Endsley (1995b), SA is "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1995b). SA describes a variety of cognitive processing activities that are crucial to dynamic, event-driven, and multitask fields of practice. Some of the cognitive processes that may be invoked under the label of SA are control of attention, mental simulation, directed attention, and contingency planning (Sarter & Woods, 1995).

According to Smith and Hancock (1995), SA is defined as adaptive, externally directed consciousness, and as such SA generates purposeful behaviour in a specific task environment. SA represents the capacity to direct consciousness to generate competent performance given a particular situation as it unfolds. SA is seen to be directly related to stress, mental workload, and other energetic facets of consciousness (Smith & Hancock, 1995).

Acquiring and maintaining SA becomes increasingly difficult as the complexity and dynamics of the environment increase. In dynamic environments many decisions are required across a narrow space of time, and performance is dependent upon an ongoing and up to date analysis of the environment. The state of the environment is constantly changing, often in complex ways, and so a major part of an operators role is obtaining and maintaining a high level of SA. Operators must also understand what they are perceiving, and so SA incorporates the operators understanding of the situation as a whole, forming the basis for decision making (Endsley, 1995b).

In terms of acquiring and maintaining SA, it has been assumed that active involvement in a task would promote the acquisition of SA. Some interesting data pertaining to SA in an analysis of 311 incidents in commercial aviation were published recently (Jentsch, Barnett, Bowers, & Salas, 1999). This study found that the captain was more likely to lose SA when manipulating the controls than when the first officer was the pilot flying. Rather than supporting the hypothesis that active involvement in the control task enhanced SA, the results of this study suggest that the additional workload of actually flying the plane reduced the captain's ability to maintain high SA of the global scenario in a problem situation. That is, flying the aircraft demands cognitive resources and thus reduces the resources available to the captain for building and maintaining SA (i.e., collecting, analysing, and communicating information). This is an hypothesis that requires experimental validation. In this sense, aviation is a unique field in that the team leader also regularly engages in active control of the aircraft. In contrast, the captain of a ship would

rarely engage in active control of the ship, but rather would provide guidelines for junior team members to execute (Jentsch et al., 1999).

A recent model of SA in dynamic systems highlights the role of SA in system performance (Endsley, 1995b). This model clearly shows that the attainment of SA occurs prior to any decision being considered or made. According to Endsley, SA is comprised of three levels. The first level involves perceiving the status, attributes, and dynamics of the key elements in the environment. For example, drivers would need to perceive elements such as other vehicles or obstacles on the road, and their dynamics, relative to the status and dynamics of their own vehicle. Level 2 SA involves a comprehension of the current situation that extends beyond being aware of the key elements that are present in the environment to gain an understanding of the significance of those elements in light of the current goals. This model suggests that synthesis of the elements from level 1 allows the operator to form patterns between the elements, and to comprehend the significance of the objects and events within the environment. An example provided by Endsley is that a military pilot must comprehend that the appearance of enemy aircraft within a certain proximity of each other and in a particular location indicates certain things about their objectives. Operator experience becomes more critical for level 2 SA. An inexperienced operator may be able to identify the key elements in the environment (level 1), but may be less able to integrate those elements with the current goals to form an adequate comprehension of the situation. The third and highest level of SA is the projection of future status. The ability to project the future action(s) is achieved through the knowledge of the status and dynamics of the elements (level 1) and comprehension of the situation (level 2). Referring again to the pilot example, knowing that an enemy aircraft is in a particular location and proximity allows the pilot to project that the aircraft is a threat and is likely to attack (level 2). This awareness provides the pilot with the knowledge necessary to decide upon the most appropriate course of action. Analysis of Endsley's model shows clearly that SA goes far beyond merely perceiving information in the environment. SA does impact upon decision making, and also affects performance.

There are a number of factors that can affect SA, which can be classified in two broad categories, and will only be mentioned briefly here. Human properties that underlie SA include preattentive processing, attention, perception, working memory, long term memory, the development of mental models, confidence, automaticity of processing, and goals. There are also task and system factors that may affect SA, which include system design, interface design, stress factors (heat, noise, etc), workload, complexity, and level of automation (Endsley, 1995a).

Managing the attentional and conceptual processes that permit strong SA involves significant cognitive resources, and as such, acquiring and maintaining SA must be appreciated as an integral part of the operators mental workload (Adams, Tenney, & Pew, 1995).

2.2.2.2 *Team situation awareness*

Team SA is more complex than combining the SA of individual team members - it involves individual SA and team processes. Models of both individual SA and team processes are dynamic, meaning that the relationship between the two is not simple. To facilitate the development of team SA, team members need to have information that will allow them to develop relevant expectations about the team task (Salas, Prince, Baker, & Shrestha, 1995).

Instructional training for shared SA and decision-making is not well developed (Paris et al., 2000). Each team member perceives one or more parts of the complex environment, which must be integrated with the perceptions of other team members. The goal is to have team members sharing a common picture of the environment, with the possible exception being situations of high uncertainty (see section 2.2.2). Team members must therefore communicate effectively to promote collective awareness of the environment and make timely and accurate reports of any potential problems. Training that develops these abilities, and shared perceptions of critical task dimensions, will improve the teams' SA.

While there is much about team SA that is not understood, there does seem to be agreement in the literature that at least one dimension of teamwork, communication, is related to team SA, while several other variables such as planning, self-critique, and task allocation are also seen as important (Salas et al., 1995). It has been suggested that initially two critical measures for team SA should relate to individual SA and the team processes that the team members use to enhance team coordination. Shared mental models (discussed in the following section) are thought to be important components of team SA and thus compatibility of mental models among team members should be measured (Stout, Cannon-Bowers, & Salas, 1994). For the team training of SA it has been suggested that training should focus on complex communication and team planning (Salas et al., 1995).

Perhaps not surprisingly there is much to learn about what and how to train for team SA. In terms of what to train, for teams with high turnover it has been suggested that training should focus on task-specific competencies, that is, the roles in the team and the significance of those roles for team performance, rather than on competencies for a specific team (Cannon-Bowers et al., 1995). With regard to how to train, the issues are how to train the necessary complex communication behaviours needed to share situation-relevant material, and how to develop the required team knowledge (Salas et al., 1995). Practice with feedback has been identified as being important for training transfer, although the influence of length of practice, type of tasks, and team member proficiency on communication behaviours has not been established (Prince, Chidester, Bowers, & Cannon-Bowers, 1992; Salas, Dickinson, Converse, & Tannenbaum, 1992). Finally, further research needs to resolve the issue of optimum degree of overlap in team member's perceptions of SA. While the majority of the literature supports the belief that a goal should be to have common SA amongst team members, recent work has suggested that divergent perceptions of SA within a team may benefit team performance in particular

situations such as those involving high uncertainty. Clearly this issue needs to be explored further if effective training programs for team SA are to be developed.

2.2.3 Shared mental model

In accordance with Klein (2000) the third cognitive process is a team's shared mental model. It should be stated at the outset that the terms mental model and knowledge structures are used interchangeably in the training literature. The shared mental model represents the second type of team knowledge as described by Cooke et al (2000).

There are several interpretations of the concept of the shared mental model. Some researchers define mental models as being part of working memory and constructed from individual background knowledge, while others suggest that mental models exist within long-term memory, or a network of associations between domain concepts (Langan-Fox, Code, & Langfield-Smith, 2000).

The concept of the mental model assumes that knowledge is organised in structured and meaningful patterns that are stored in memory (Johnson-Laird, 1983; Rouse & Morris, 1986). Mental models allow individuals to draw inferences, make predictions, and to decide upon appropriate actions (Johnson-Laird, 1983). There have been several definitions of mental models offered in the literature. A definition that appears well accepted is that mental models are a mechanism that enables people to generate descriptions of system purpose and form, explanations of system functioning, and predictions of future system states (Rouse & Morris, 1986). Similarly, Wickens et al. (1998) suggest that mental models are internal representations of objects, actions, situations or people, built on experience and observation, and are simulations that are run in operators minds that allow them to describe, predict, and explain behaviour.

A team has a shared mental model to the extent that team members have the same understanding for the dynamics of key processes. These processes can include the roles and function of each team member, the nature of the task, the use of equipment, and so on. Of particular importance is the degree to which team members have a shared mental model of their own roles and functions, because a common source of difficulty occurs when team members are confused about who is doing what. The shared mental model refers to the configuration of the team and the way it is supposed to perform routines, whereas shared SA refers to the current and projected situation (Cannon-Bowers, Salas, & Converse, 1993; Schraagen, Chipman, & Salin, 2000).

A team mental model reflects the dependencies or interrelationships between team objectives, team mechanisms, temporal patterns of activity, individual roles and functions, and relationships between individuals. Shared mental models therefore allow crew members to implicitly and more effectively coordinate their behaviours, as they are better able to recognise the individual responsibilities and information needs of fellow crew members, monitor their activities, diagnose deficiencies, and provide support, guidance, and information as needed (Paris et al., 2000).

Research is not conclusive regarding what should be the content of shared mental models, and the nature and extent of information that must be shared to allow the team to form accurate explanations and expectations of team performance. At what point do team member's knowledge and expectations overlap so much that the uniqueness of individual contributions is lost? (Cannon-Bowers et al., 1993).

Human factors and ergonomics specialists have developed a heavy reliance upon mental models. The belief is that if the mental models from operators in particular situations can be communicated to the system designers, then the systems can be designed with interfaces that better match the needs and expectations of the operators (Wilson, 2000). Similarly, training systems can be designed to build up mental models consistent with that of the expert. As discussed later, shared mental models also form the basis for theoretical frameworks of team decision-making (Orasanu & Salas, 1993).

2.2.4 Strategies

While not a process *per se*, Klein (2000) states that a team develops strategies and heuristics to make decisions and problem solve as it gains experience. Despite lists of steps and procedures, most teams will learn strategies (and shortcuts) that are not in the procedures. That is, a skilful team will learn who the key decision makers and sources of expertise are. Klein (2000) suggests that if we are to attempt to better understand team functioning then is it important to consider the strategies that the team has developed for moving information and ideas, and for assimilating the various sources of information.

2.2.5 Metacognition

The final process is metacognition, which encompasses a teams need to monitor itself and determine when difficulties are encountered, how the difficulty is linked to its vulnerabilities and limitations, and where it needs to shift its strategies (Schraagen et al., 2000).

Metacognition can refer broadly to a reflective executive function, which encompasses defining a problem, devising a plan to solve it, and deciding what information and resources are both required and available (Orasanu, 1993). Effective teams can self-monitor and make changes. Ineffective teams usually are unaware why they are getting in their own way and so are in no position to adapt operations to improve performance (Schraagen et al., 2000). It would appear intuitive that the process of metacognition would be more effective when the team had well developed shared mental models and SA.

2.2.6 Team Decision-Making

Decision-making is another key team process, and the literature concerning team decision-making invokes many of the team processes discussed above, such as shared SA, shared mental model, and metacognition (Orasanu, 1993), and so is worth talking about here. This

highlights one of the difficulties in assimilating the literature on these cognitive processes in that there is a considerable degree of overlap between them.

Experts come to see the world in terms of patterns that develop with experience. This reduces workload but also facilitates more rapid action. Given that pattern recognition is important, how should it be trained? Simulation can be used because it can create many practice trials that are designed to build up the recognition of patterns that can be constantly adapted to the trainee in terms of the level of difficulty for instructional purposes (Means, Salas, Crandall, & Jacobs, 1993). Means et al. (1993) suggest that training of metacognitive skills (reflection upon, and regulation of, one's own thinking) may be the best option for generalisable skills that will aid team decision-making.

The concept of shared mental models becomes a means of defining the determinant of team attentional capacity. If shared models are consistent then team capacity should be enhanced because there will be less process loss. If they are inconsistent then misunderstandings and thus failures may occur (Duffy, 1993).

2.2.6.1 Naturalistic Decision-Making

In the previous decade there has been a paradigm shift in decision-making research, with a shift towards the study of decision-making in naturalistic settings (NDM). This shift is away from classical decision-making research which was seen as often focussing on sterile and contrived decision-making situations with results that were of little consequence to real world decision makers (Beach & Lipshitz, 1993). The focus has shifted to study decisions that are embedded within complex tasks and that are made by competent and experienced decision makers.

A number of factors have been identified that characterise decision making in naturalistic environments (Orasanu, 1993). Some or all of these factors need to be present for a decision to be considered naturalistic. These factors are: ill-structured problems; uncertain, dynamic environments; shifting, ill-defined, or competing goals; multiple event-feedback loops; time constraints; high stakes; multiple players; and organisational norms and goals that must be balanced against the decision makers' personal choice.

The NDM approach has made some important contributions to the study of decision making (Klein, 1993). It has emphasised how decision makers bring their experience to the fore in making a decision, it broadens the focus of decision-making research, and the models associated with NDM emphasise the different cognitive strategies and processes that are used when a decision situation is viewed as a temporal (rather than static) event. Moreover, NDM has provided researchers with a new method for studying decision-making processes.

A major theory in the area is the recognition-primed decision model (RPD) which describes how experienced operators make decisions in natural settings (Klein, 1993). The decision maker identifies the situation as typical, which allows the person to know certain points, such as which goals make sense, which cues are relevant, what to expect, and

which actions typically work. The decision maker can then implement an appropriate course of action without further deliberation. For more complex situations, the decision maker can appraise the possible courses of action by choosing the first one and running mental simulations and evaluating how that action will unfold in the given context. In most cases it is the first chosen course of action that is simulated and accepted to be put into action. Support for Klein's RPD model is found in studies examining decision making of pilots (Endsley & Smith, 1996) and offshore oil workers (Flin, Slaven, & Stewart, 1996) to name a few. Klein's RPD model emphasises the importance of SA for successful decision making in field settings.

This model does have applied implications, particularly for training interventions to facilitate the transition from novice to expert decision maker. Since pattern recognition is a key element in the decision making process (Klein, 1993), it has been suggested that interface training interventions support the development of highly effective and robust heuristic strategies rather than the development of abstract and cognitively intensive strategies (Kirlik, Walker, Fisk, & Nagel, 1996). These authors were able to show the benefits to decision making skill acquisition from training techniques that involved concrete situational patterns in the task environment, and from augmented displays that enhance critical perceptual properties and relationships during training.

The importance of metacognition in decision-making is emphasised in the recognition/metacognition (RM) model of decision making (Cohen, Freeman, & Wolf, 1996). This model appears to be an extension (of sorts) from Klein's model of decision making which was based largely on recognitional processes (Klein, 1993). This model highlights two strategies: recognition of expectations and associated responses; and the critiquing and correcting of those responses. This latter point is linked with the concept of metacognition, that is, processes that monitor and regulate other thought processes (such as memory and attention). Metacognitive skills also include verifying and improving the results of pattern recognition as part of the decision making process in uncertain situations. According to the RM model, as decision makers become more familiar with a domain, they acquire abstract knowledge about the types of events and relationships between events that are relevant in particular situations. As such, when confronted with a new situation, decision makers can draw upon this generic knowledge to integrate the new information and subject the results to repeated modification and evaluation.

With regard to team decision-making, the NDM perspective has helped by focussing attention on the processes involved in team decision-making. Other principles that have arisen from NDM that can be used to develop an expert team are: fostering shared mental models of task work and team member roles; training skills such as SA, communication, leadership, and adaptability; providing guided practice in naturalistic conditions; linking cue patterns with response strategies with regard to different tasks and team members; and training team leaders to maintain shared SA by providing periodic updates to team members (Salas, Cannon-Bowers, & Johnston, 1997).

NDM theories imply that context-specific domain knowledge is a crucial aspect of expert decision-making, and as such, training decision-makers in problem solving specific to a given domain may be more fruitful than training generic problem solving skills (Cannon-Bowers & Salas, 1997b).

2.2.7 Team processes for distributed teams

The majority of team research has involved teams that are located in the same physical space. DMT is likely to involve both co-located and distributed teams. The distributed nature of teams introduces a further level of abstraction that team members must deal with, which has been referred to as 'team opacity' (Fiore, Salas, & Bowers, 2001). In the context of distributed teams Fiore et al (2001) use this term to describe the decreased awareness of team member actions that may alter their interactions. In co-located teams the interactions between individuals are transparent in that is it easier to assess the actions of other team members, but the demands on working memory in non co-located teams are higher. At the team level, physical separation introduces complexity because a team process such as communication is reliant upon implicit and explicit cues, however there is likely to be a much heavier reliance on explicit cues in distributed teams (whereby gestures may be sufficient in co-located teams for some forms of distributed team communication) (Fiore et al., 2001). The interactions between co-located and distributed teams are likely to be quite different.

While there is some understanding of team processes such as communication and shared mental models, considerably less is known about distributed cognition, that is, what information a distributed team uses to effectively perform the task, and how the placement of team members in separate locations may alter the requirements of effective (co-located) teams. Fiore et al. (2001) suggest that perhaps the development of shared mental models in distributed teams is the most significant consequence of the distributed interactions, as the development shared mental models is heavily reliant upon communication.

Fiore et al. (2001) therefore suggest that increased emphasis should be placed on communications that occur outside of the distributed exercise, that is, pre and post-exercise. They suggest that distributed interactions may be facilitated by pre-exercise coordination efforts, and group development exercises and cross-training may be appropriate here (cross-training is discussed in more detail in section 3.2.2). Post-exercise coordination efforts, such as team self-correction, may also be helpful in the development of team processes, but may also help the development other important team attitudes such as trust and cohesion (Fiore et al., 2001). The lack of literature in the field indicates that research examining the factors that contribute to the effective functioning of distributed teams is in its infancy.

Critical processes for team functioning have been discussed, and well as the difficulties facing distributed teams. The question now is how to go about identifying and defining these cognitive processes for complex performance.

2.2.8 The analysis of cognitive processes

The analysis of complex skills and their associated knowledge requirements is a major problem for training. Taxonomies, such as Hierarchical Task Analysis (HTA), are useful, but use relatively global categories and do not include how to analyse the detailed psychological components of skill (Patrick, 1991).

There are many types of knowledge that underpin performance of a complex task. All of these types of knowledge need to be identified, described, and assembled in order to produce a complete analysis. There are many constructs in cognitive psychology to describe knowledge representation. It is well beyond the scope of this report to review these cognitive concepts and so they will be mentioned only briefly here. Further details can be found in texts on cognitive psychology.

In procedural knowledge the concept of a schema (a cognitive mechanism that helps in the organisation of knowledge) is important in explaining how experiences are organised in memory, how new information is assimilated, and how actions are organised in familiar situations. The acquisition of rules has been another means by which to characterise cognitive performance (e.g., Anderson, 1982). More recently the concept of the mental model has been invoked to encompass anything from the simulation of a cognitive activity to something resembling the notion of a schema (Johnson-Laird, 1983; Rouse & Morris, 1986). Other approaches have described rules of thumb or heuristics that experts use in performing a complex cognitive task which need to be verbalised to facilitate the progression from novice to expert performer. Clearly there are many types of knowledge involved in the performance of complex cognitive tasks and many concepts invoked in cognitive psychology to account for them. There is however no clear mapping between the type of task to be analysed and the psychological constructs used (Patrick, 1992).

The analysis of a cognitive task should result in a model of how an expert performs that task, and the different types of knowledge involved and their associated representations. This is difficult because experts have the ability to switch between different types of knowledge and use them almost simultaneously during performance of a task. Rasmussen (1986) has made some progress in this area in considering the human operator in complex systems. He identified two dimensions that can be used to map types and levels of knowledge involved in performance. The first dimension of aggregation refers to the size of the unit under consideration, for example, whole system through to individual components. The second dimension is abstraction, of which there are five levels: system purpose relates to objectives and constraints of the system; abstract function represents the function of the system; generalised function includes description in terms of standard functions and process; physical function includes mechanical, electrical, etc processes of the system and part; and physical form is the actual physical appearance and configuration of the system and parts. Rasmussen (1986) provides examples of descriptions in the means-ends abstraction hierarchy for manufacturing and computer systems. The operator moves between different levels during task performance, as

determined by the nature of the task, and different types of knowledge are required to support performance at each level. The dimensions of aggregation and means-ends can be combined to show the progression of cognitive behaviour during the performance of a task (see Patrick, 1992).

It is however not possible to perform a full and coherent psychological analysis of a complex task. To understand human expertise more generally will involve more empirical and simulation research (Anderson, 1982). In light of this it would seem that a mixture of top-down and bottom-up approaches might be optimal at this point.

2.2.8.1 Approaches to Cognitive Task Analysis

The grouping of required competencies in section 2.1 was cognitive, behavioural, and attitudinal. Of great interest in this review are the cognitive competencies. Behavioural accounts of team performance identify which team member is responsible for each subtask, show how responsibility for a subtask changes through the performance cycle, and helps in the observation of the team and whether the team is following procedures. Behavioural accounts do not however help in understanding how the team was interpreting the situation, how the team made decisions, how team members might have been confused about their roles and functions and those of others, or how the team self-monitors so it could adapt when necessary (Schraagen et al., 2000). Cognitive approaches, such as Cognitive Task Analysis (CTA), can help to describe the way a team is thinking rather than the steps it is following. This information can then be used to inform the development of training programs.

There are many different CTA techniques that have been used to identify the cognitive demands and activities underlying task performance (e.g., Schraagen et al, 2000; Kirwan & Ainsworth, 1992; Gordon & Gill, 1997). Some of these techniques involve unstructured and structured interviews with subject matter experts (e.g., Militello & Hutton, 1998), knowledge elicitation procedures (Fowlkes, Salas, Baker, Cannon-Bowers, & Stout, 2000; Hoffman, Crandall, & Shadbolt, 1998), whilst others involve more formal modelling procedures. The diversity in CTA approaches potentially leads to confusion about the type of results that are expected from CTA and how the results will impact upon system design or evaluation. An important issue is that approaches to CTA are weakly linked to the design and development of advanced decision support systems (Potter, Roth, Woods, & Elm, 2000).

One form of CTA is the critical decision method (CDM), which attempts to elicit expert knowledge via retrospection. As such, to retrospect there must be an event about which one can retrospect. In distributed environments, often a particular operator may not have accurate knowledge about their performance, i.e., information from their element of the task may be passed onto another team member, but the operator may not know if the information they provided was correct. As such it is possible that the operator may be less able to refine their performance and develop expertise. People can have difficulty recalling incidents when feedback is lacking, which is not favourable for the CDM method (Hoffman et al., 1998).

Recently it has been suggested that CTA is more than the application of any single technique, and that developing a more meaningful understanding of a domain relies on multiple converging techniques (Potter et al., 2000). They contend that the focus of CTA is on building a model that captures the analysts' understanding of the task domain, the domain practitioners' knowledge and strategies, and how existing artefacts influence performance. More specifically, Potter et al. (2000) refer to CTA as a bootstrapping process that is focussed on understanding both the domain (mapping the cognitive demands of the fields of practice) and practitioners (modelling expertise and cognitive strategies) through a series of complementary (empirical and analytical) methods.

It is important to understand the domain characteristics and the cognitive demands they impose because it provides a framework for interpreting practitioner performance (what complexities in the domain are they responding to? What constraints of the domain are they less sensitive to?), and it helps define requirements for effective support (what aspects of performance could use support?) and clarifies the bounds of feasible support (what technologies can be used to support the complexities of the domain?). The second major issue to understand is how the practitioner responds to the demands of the domain. To understand effective strategies for managing demands of a domain it is critical to understand the knowledge and strategies that expert practitioners have developed in response to those demands. This understanding can highlight where support is needed (Potter et al., 2000).

An integrated approach to CTA generally requires the use of multiple converging techniques including those that focus on understanding the demands of the domain as well as those that focus on understanding the knowledge and strategies of domain practitioners (Potter et al., 2000). These are different approaches that provide complementary perspectives. Potter et al. (2000) believe that, if resources are scarce, that it is more effective to use techniques that sample both perspectives, even if cursorily, than to use all resources for one technique. The use of multiple techniques is more likely to uncover complexities and surprises, and converging results increase the confidence of understanding.

In order to overcome the problems associated with conducting CTA with new technologies (i.e., in domains that do not exist), Potter et al. (2000) advocate that the CTA process can be extended into the design and prototype development phase. An example of how this process was implemented is provided by Potter et al. (2000) and will only be mentioned briefly here for illustrative purposes. The example describes a CTA to provide design concepts for a graphic user interface for a next generation decision support system.

From a training perspective, specification of performance goals enables the identification of the knowledge required to achieve those goals. Goals can be used as the framework for a top-down analysis, and can be divided into subgoals to unravel more specific strategies and knowledge requirements. The best known descriptive model that adopts a top-down

goal-oriented approach is that proposed by Rasmussen (1986) for the analysis of decision-making tasks (Patrick, 1991).

The first step of the CTA in this case study was to build a goals-means representation of the domain (as per Rasmussen, 1986; Vicente, 1999). This functional representation specifies the underlying, unchanging system functions and relationships that form the basis for system complexity and goal achievement. The domain model is critical for understanding the context (goals to be achieved, strategies for achieving the goals) in which the practitioner must perform. It also is intended to provide a robust model of a complex environment, independent of specific events, tasks, and strategies. A claimed major benefit is that it enables identification of person-machine and inter-person information requirements to support decision making and problem solving in unanticipated situations that system designers have not explicitly foreseen or addressed. It provides a starting point in understanding fundamental relationships, scope of the application, and system objectives. The second step involved interviews with potential users of the system to understand their information needs, knowledge, and strategies. The primary use of the functional representation in this second step was as a mechanism for resolving discrepancies between different interviews. Step 3 involved refining the initial functional representation in light of the interviews conducted in step 2. The functional model therefore begins to capture some of the practitioner expertise, knowledge, and strategies. In step 4, the interviews are also used to identify critical decisions within the work domain, which must then be supported in the resulting system design. Supporting information needs and visualisation design (to support the information needs for each of the critical decisions) are the final two steps. While only mentioned briefly here, this example highlights how multiple converging techniques can be used in conducting CTA.

While the abovementioned techniques have been well documented for individual tasks, on the whole the approaches have not been well developed for a cognitive task analysis for team tasks. The ability to identify the specific behaviours that comprise teamwork is a prerequisite for effective team training, and several researchers have documented concerns regarding the validity of using measurement instruments derived from individuals in team performance research (Bowers, Baker, & Salas, 1994; Dyer, 1984). Hence a clear understanding of the team behaviours and processes is required.

Few techniques have been used to identify team skills and processes. Annett, Cunningham, & Mathias-Jones (2000) describe the use of Hierarchical Task Analysis for Teams (HTAT) to identify team skills required by anti-submarine warfare teams. The HTAT approach involves decomposing team goals into subgoals, and then identifying subgoals which can only or best be achieved by teamwork (Annett & Cunningham, 2000; Shepherd, 1998). Teamwork was defined as communication between, and the coordination of actions of, members of the team.

Perhaps the best technique to capture the five cognitive processes for teams discussed earlier and defined by Klein (2000) is a team CTA. Klein and colleagues have used this technique to examine the cognitive processes in US Marine Corps command posts and

nuclear power plant emergency response teams. Typically a team CTA is conducted primarily via interviews with subject matter experts, however both observations and simulations of team behaviour can also be used. The goal of team CTA is to collect information concerning the manner in which teams make decisions and the way the team is managed. By gaining an understanding of these issues it is possible to further explore the five team processes in more detail. Specifically, a team CTA needs to address how the team manages information, how it attempts to maintain shared SA, the extent to which mental models are shared, the strategies and expertise the team has developed and learned, and the extent to which the team is able to identify and manage problems.

Finally, Cognitive Work Analysis (CWA) is another form of CTA that is used to model, analyse, and design complex systems (Rasmussen, Pejtersen, & Goodstein, 1994; Vicente, 1999). The first stage of CWA is Work Domain Analysis (WDA). WDA is conducted at the functional (rather than behavioural) level and describes the boundaries of the work domain that shape behaviour. Within the boundaries of the work domain the operator uses the available resources to engage in a variety of actions in order to achieve the system goals. By focussing on the functional structure of a system, WDA is independent of task-type or specific behaviours, and is therefore valid across a range of situations (Vicente, 1999). As such WDA is suitable for military environments in which a number of different tasks may be performed in order to reach a particular goal, and where initiative and adaptive behaviour are encouraged (Braithwaite, 2002).

WDA identifies the functional structure of a system, and thus provides a framework for designing training systems that support adaptive behaviour. If a training system is modelled on the functional structure of the work domain, then the training system would be able to provide trainees with the same possibilities for action that would be available to them in real world training environment (Naikar, Sanderson, & Lintern, 2000).

WDA has been used within DSTO to identify training functions for both training simulators (Naikar et al., 2000) and team training (Braithwaite, 2002). This latter study used WDA to identify team training functions for Combat Training Centre (Live) (Braithwaite, 2002).

The aim of CTC-Live is to provide collective training in a realistic and challenging battlefield environment (i.e., to prepare Combat Team and Battle Group as combined arms teams for combat in a realistic joint environment in order to enhance war fighting operations). The study was conducted in support for the acquisition of an instrumentation system called CTC Live Simulation, Range Instrumentation and Information System (CTC-LIS). WDA was used to identify the training needs for CTC-LIS, and then the training functions were analysed to identify the operational requirements for those training functions.

Some of the objectives of CTC-Live are analogous to those for DMT, including:

- Force generation – increase unit readiness for deployment and war fighting;
- Facilitate the evaluation of readiness levels for the combat force;

- Train and evaluate combat leaders and combat teams in a realistic battlefield environment;
- Provide a mission rehearsal capability; Provide objective measurements of performance, feedback, and reinforcement of lessons learned, and;
- Contribute to the evaluation of operational concepts.

The steps involved in the study by Braithwaite (2002) involved developing an abstraction hierarchy of the combat team, using that to identify training functions for the team, and extrapolating operational requirements from the training functions. This project was able to identify the functions that must be supported by the training system design, rather than technical or design specifications. The potential for the use of WDA in defining training functions within the RAAF DMT system should be explored.

3. Theoretical perspectives on learning and instructional strategies for team training

There is a vast literature on theories of learning and instructional strategies for training. Training programs should be informed by relevant theory, and hence an understanding of the theoretical perspectives is needed before discussing training methods that have been used. This section of the report is divided into two distinct segments. The first segment considers the prominent theoretical perspectives on learning and skill acquisition. The second segment then considers the range of instructional strategies for training.

3.1 Theoretical perspectives on learning and skill acquisition

In order to foster effective learning, the design and structure of a training program should be informed by theory relating to learning and skill acquisition. The theory of skill acquisition proposed by Anderson (1982) has become prominent in the training literature. The stages of skill acquisition described in Anderson's theory of cognitive skill acquisition are similar to those in Fitt's three-phase theory (Fitts, 1964, 1965), although the hypothesised processes responsible for the transition from novice to expert are quite different from those proposed by Fitts. While the majority of this section will focus on Anderson's theory, it is helpful to consider the earlier work of Fitts.

Many reviews are in agreement that the three-phase theory proposed by Fitts has been the most influential theory of skill acquisition in the area of training (Annett, 1991; Patrick, 1992). Fitts (1965) described the development of skills as the progression through three phases: the cognitive phase; the fixation or associative phase; and the autonomous phase. The transition from one phase to the next was believed to be a continuous process.

The cognitive phase of Fitts' theory represents the initial cognitive processes involved in the learning of a new task. Both the trainer and trainee attempt to verbalise what has to be learned. While expectations and procedures are explained, performance by the trainee is error prone and further guidance is required from the trainer. For complex tasks it is important that the trainee understands what is involved in the task before it can be attempted. In addition to learning rules and procedures governing what is permitted, the trainee learns how a task might be executed (i.e., develops understanding). In the second associative phase, practice and the reduction of errors leads to correct patterns of behaviour being established. In the final autonomous phase skilled performance becomes more automatic, requiring reduced psychological resources such as memory and attention. In fact, the trainee may be unable to verbalise how the task is performed suggesting that aspects of behaviour can be executed without conscious awareness.

The more recent Adaptive Components of Thought (ACT) theory proposed by Anderson (1982) develops Fitts' concepts and explains how skill acquisition is a process of developing and refining production rules in the transition from declarative to procedural

knowledge. It is assumed that experts have a greater number of more detailed and accurate production rules than novices. It should also be stated the declarative knowledge is factual knowledge that can be stated and made explicit, whereas procedural knowledge is implicit and often hard to verbalise, and is concerned with how to perform a task (i.e., declarative knowledge is 'knowing that' whereas procedural knowledge is 'knowing how' – the cognitive basis for skilled performance). This theory has three stages that are outlined below: the declarative stage; the knowledge compilation stage; and the tuning stage.

The first stage of the ACT model describes when the trainee only has limited declarative knowledge (i.e., facts) about the task and uses this knowledge in conjunction with general problem solving procedures to attempt task performance. Performance at this stage often relies on analogies, may make high demands on attention and working memory, and may be slow, error prone, and effortful. Anderson (1982) also makes the point that a contributor to poor performance at this stage often relates to instructions given to the trainee. That is, instructions often do not specify how to perform that task. Procedural knowledge will develop as the trainee develops appropriate procedures for task performance through practice.

By the end of the second knowledge compilation stage specific procedural knowledge (via developed production rules) has been built up by the trainees. Knowledge compilation is a process by which declarative knowledge is translated to procedural knowledge. The first process in knowledge compilation is composition, which is a process by which adjacent production rules are merged into a single rule. Proceduralisation is the second process which enables a production rule to incorporate more task relevant information. The major advantage of proceduralisation is that information no longer has to be recalled to working memory in order to execute these rules (i.e., reduced demands on working memory). The third and final stage is the tuning stage in which further improvements in skilled performance are achieved as rules and skills are adjusted and fine-tuned.

Skill acquisition is facilitated by the development and refinement of production rules, and this is achieved by 'doing' the task (Anderson, 1982). Training therefore should identify and pass on the rule structure underlying task performance thus facilitating the development of task-specific procedures. The higher the quality of training material the lower the degree of effort required by the trainee – although no matter how high quality the training is, it is critical that the trainee internalise the production rules through practice and modify them as the task and environment change.

Like other theories of skill acquisition (e.g., Ackerman, 1987; Ohlsson, 1996), the ACT theory assumes that learning has to progress through a declarative stage before procedural knowledge can be achieved. As reviewed by Patrick (1992) & Annett (1991), there have been some researchers who have argued that some knowledge is implicit (cannot be verbalised) rather than explicit, and hence that implicit knowledge may be acquired differently from explicit knowledge as it does not involve a transition from working memory to long-term memory. Anderson's theory however does emphasise that specific

procedures can eventually be executed automatically, thereby emphasising a cognitive basis for skill acquisition.

The basic distinctions made in the ACT theory can also be used to generate predictions concerning transfer (Holding, 1991). Applying similar procedures to the same declarative knowledge should lead to good transfer across different tasks, however the same declarative knowledge may not be very useful if different procedures are required. Production rules (i.e., procedural knowledge) can mediate transfer directly through their application to a range of different cognitive operations.

There are a number of implications arising from this model. The first is that expertise is domain specific. In dealing with content customary for their work, experts use domain-specific methods tailored to their field, rather than more general problem-solving procedures. In short, it is how novices and experts use their domain-specific knowledge that distinguishes them. Secondly, an expert's knowledge is highly proceduralised and linked to actions and conditions of applicability. That is, it is difficult to separate what an expert knows from how that knowledge is used (Means et al., 1993).

There are clearly some similarities in the three stages of the ACT model and those of Fitts' three-process model of skill acquisition. This declarative and procedural knowledge distinction is also the basis for other theories and prominent models of information processing (Meyer & Kieras, 1997). A criticism of both theories is that they are descriptive rather than prescriptive and as such do not allow for predictions relating to the duration of the stages of acquisition of a particular skill (Patrick, 1992). Nonetheless, they have been prominent frameworks in the psychological literature relating to skill acquisition, and they provide a means of conceptualising the process of skill acquisition, and thereby provide inputs into training design.

A more recent learning theory by Ohlsson (1996) attempts to explain how people are able to detect and correct their own performance errors. The basic principles of this theory are that errors are caused by overly general knowledge structures, that error-detection requires domain-specific declarative knowledge, that errors are experienced as conflicts between what the learner believes ought to be true and what he or she perceives to be the case, and that errors are corrected by specialising faulty knowledge structures so that they become active only in situations in which they are appropriate. This theory is limited to the acquisition of complex skills that have significant cognitive component.

Two major cognitive functions involved in learning from errors are error detection and error correction. With regard to error detection, in order to learn from an error one must be able to detect it, or be aware of the error. In many training situations immediate feedback is available via learning software or tutors. It is less clear how learners in unsupervised situations evaluate their work and are able to detect errors. Whilst not a new idea in psychological research, Ohlsson develops the idea that errors are detected in novices by comparing actual with expected outcomes. The emphasis here is on the subjective view of errors rather than the objective view of errors (whereby errors are

deviations from the correct action). To be informative during learning, errors must be recognisable to the trainee before they have attained mastery of the target skill.

Errors are recognised via particular features of the situations they produce. Error signals is the term given to describe the features or patterns of features that indicate incorrect actions. An example of an error feature would be when a learner driver heard grinding noises in the gearbox of a vehicle. The recognition of error signals requires domain-specific knowledge. The learner must have some knowledge about the range of reasonable actions or responses in a given situation in order to recognise an action as being incorrect or unreasonable. As such, errors appear subjectively as conflicts between what the learner believes, through prior knowledge, should be true and what the learner perceives to be the case.

Briefly, Ohlsson also discusses the distinction between practical and declarative knowledge. This distinction is necessary to account for the fact that if a learner has sufficient knowledge to recognise an action as being incorrect, then why was that incorrect action performed in the first place. If an error is started but then recognised and corrected, then there may be a monitoring mechanism of behaviour that is separate from the mechanisms responsible for the selection and execution of the action (Norman, 1981). The dissociation between execution/action and monitoring/evaluation can be understood by considering the distinction between practical and declarative knowledge. The function of practical knowledge is to generate and organise action. The functions of declarative knowledge include explanation and prediction. Ohlsson suggests however that declarative knowledge is prescriptive rather than descriptive, and that the cognitive function that supports it is not explanation or prediction, but judgement, which allows the learner to evaluate the outcomes of their actions. So in short, the function of practical knowledge is to generate actions, and the function of declarative knowledge is to support judgement. The existence of two distinct knowledge bases can be used to explain why a trainee can perform an action that they recognise as being an error as soon as they perceive the outcome.

With regard to error correction, Ohlsson's theory describes displacement errors, which are errors caused by overly general practical knowledge. Initially a learner's behaviour is controlled by general methods and rules that are non-restrictive and do not take into account the structure of the particular task environment. These rules are minimally restrictive and so will be active in many situations and therefore have a high probability of being active in situations in which they are not appropriate. Individuals engage in complex reasoning (blame assignment and error attribution) considering how and why an error occurred, and then revise rules, making them more specialised, and limiting their application to situations that will produce desirable outcomes. This hypothesis has strong similarities to the process of rule revision discussed by Anderson (Anderson, 1982). Ohlsson concedes that these hypotheses are tentative due to a lack of empirical evidence, but that a conceptual advance is that the processes of error attribution and knowledge revision are cognitive functions that must be specified to explain how novices unlearn performance errors.

Basically, we approach novel situations with (general) declarative knowledge, and through experience making and correcting errors, procedural knowledge is constructed (i.e., as production rules become more specialised and modified they become more specific to a task environment). So it is declarative not procedural knowledge that is transferred in novel situations. This progression from declarative to procedural memory and the development of production rules is similar to that discussed by Anderson. With regard to instruction, Ohlsson's theory would suggest that feedback be given to the trainee which should focus on the trainees faulty reasoning and the correct reasoning, rather than simply providing the correct answer. In other words, feedback should focus on the recognition of conditions and expectations which should have been generated in the situation in order to promote the transfer of higher-order declarative knowledge.

3.1.1 Implications of learning theory for measuring performance during training

Kraiger et al. (1993) comprehensively reviewed the literature concerning cognitive learning and drew inferences for training outcomes. In doing this they suggested three general categories of cognitively based measures of evaluation, being verbal knowledge, knowledge organisation, and cognitive strategies. These measures are organised, generally speaking, to reflect the development and changing of trainee knowledge.

Most theories of cognitive skill development state that the acquisition of declarative knowledge is a necessary condition before acquiring higher-order procedural knowledge and refined strategies or production rules (e.g., Ackerman, 1988; Anderson, 1982). As such, a measure of declarative knowledge may be more useful to gauge learning in the early stages of training. Declarative knowledge can be measured via multiple-choice or free-recall examinations, however Kraiger et al (1993) concede that trainee intelligence may confound overall training success, i.e., more intelligent trainees will gain declarative knowledge more quickly but is this initial edge predictive of success in subsequent training? The point here is though that tests of declarative (knowing that) knowledge are going to be more value towards the beginning of the training regime, and hence may not accurately reflect higher-order knowledge of more advanced trainees or those who have completed training.

As training progresses there is a shift towards the acquisition of procedural knowledge, which is associated with the development of knowledge structures. As discussed in earlier sections, the concepts of knowledge organisation and mental models are prominent in the literature. As will be discussed in a later section, researchers have been attempting to develop reliable measures of mental models, and relating knowledge organisation to task performance.

Finally, as proposed by Anderson (1982), skill development is a continuous process, and so as declarative and procedural knowledge is developed, task strategies become more refined and efficient. As discussed elsewhere, more efficient and internalised strategies

free up cognitive resources for other executive functions. As discussed earlier, the concept of metacognition encompasses the planning, monitoring, and revision of task-oriented behaviours, and an understanding of the relationship between task demands and individual level of capability (Kraiger et al., 1993). The measurement of metacognitive skills requires high-level and in-depth examinations with subject-matter experts to gain an appreciation for the steps necessary to problem solve and to progress towards an objective.

Having reviewed some of the major theoretical perspectives on learning, the following sections discuss techniques that have been used in the literature to inform the design of training programs.

3.2 Instructional strategies for team training

Instructional strategies are the techniques that are used to develop and maintain required competencies. Instructional strategies draw together the tools for training and the methods of delivery to create an environment for effective team training. Salas & Cannon-Bowers (2000) present a review of 'exemplary' (instructional) strategies that have emerged from the literature. While the Instructional Systems Design (ISD) approach & the Event Based Approach to Training (EBAT) seem to be most appropriate for high technology environments, this section of the report initially focuses on reviewing a wide range of approaches to team training.

Team training strategies result from the combination of team training tools and methods. The tools of team training include team task analysis, performance measures, feedback, task simulations and exercises, and principles of learning, training and team performance. The methods include information-based (i.e., lectures), demonstration-based (i.e., videotapes), and practice-based methods (i.e., roleplay and simulation). Guided by the training objectives, the content (knowledge, skills, attitudes), tools, and methods, in combination, shape the strategies (Salas & Cannon-Bowers, 2000). Some of these strategies are discussed briefly below.

3.2.1 Team Coordination Training

Team coordination training is the most common form of team training, and is known as Crew Resource Management (CRM) training, Aircrew Coordination Training (more in military settings), or Team Adaptation and Coordination Training. While these approaches have been useful in aviation, military, medical, and industrial settings, there are some common features despite the differing contexts, such as:

- Team coordination training is focussed on general team training objectives;
- They are drawn from general frameworks of team performance or group dynamics;
- They use tools such as simulation, principles, guidelines and specifications, along with feedback;

- They combine information-based methods (presentations), demonstration-based (passive observations of behaviour), and practice-based methods (role playing to simulation); and
- They are usually short duration (2-5 days).

There has been much research aimed at the development and evaluation of CRM training. CRM training is an example of this type of instructional strategy in commercial aviation, whereby cockpit crews are trained on the importance of teamwork and team performance in an attempt enhance error management (Helmreich, Merritt, & Wilhelm, 1999). The claimed outcome is that crew members learn to make better use of the team resources, with the aim of minimising human error caused by inadequate coordination among teams, which is particularly critical in emergency situations (Wiener, Kanki, & Helmreich, 1993). CRM training has lead to a shift in aviation training towards the social interactions within the cockpit, or in other words, team coordination (Salas, Prince et al., 1999). CRM training has also been defined as a family of instructional strategies that seek to improve teamwork in the cockpit by applying well tested training tools targeted at specific content (Salas, Rhodenizer, & Bowers, 2000). In accordance with Anderson's ACT theory, one criticism of CRM training is that because it is predominately lecture-based, it will effectively provide declarative knowledge, but not the transfer to procedural knowledge that comes with practice and experience (Salas et al., 2000).

The FAA recommends that CRM training be broken into three phases; a), an awareness phase in which crew members attend seminars and group exercises to learn the basics of CRM; b), practice and feedback phase in which the crew members fly realistic simulator scenarios and receive feedback on their performance; and c) a reinforcement phase in which the concepts become part of the organisations overall training and operational practices (Prince et al., 1992). The practice and feedback is usually provided in the form of Line Oriented Flight Training (LOFT), in which a high fidelity simulator is flown with a complete crew as if on an actual line flight. All preparations, paperwork, communication, and routine procedures that are part of normal flight, are included in the simulation. Each LOFT session would normally contain a system failure or weather problem for the crew to resolve. Crew performances are videotaped and then reviewed by the instructor and trainees.

While CRM has predominantly been researched and applied within commercial aviation, some CRM research has concerned military aviation (Salas, Prince et al., 1999; Spiker, Tourville, Bragger, Dowdy, & Nullmeyer, 1999; Thompson, Tourville, Spiker, & Nullmeyer, 1999). Over nearly a decade of research, Salas et al (1999) attempted to study CRM in the context of Navy (rotary wing) aviation in a systematic fashion. CRM was defined as a set of teamwork competencies that allow the crew to cope with situation demands that would overwhelm any individual crew member. These authors advocate an EBAT as the best methodology for developing effective CRM training. EBAT is discussed in detail in a later section. Their CRM instructional strategy involved lectures, video-taped models of correct and incorrect behaviours, and demonstration via opportunities to practice on carefully scripted scenarios (as informed by the EBAT process), tracking of

performance, and finally feedback. They state that the advantages of EBAT for CRM training are that the training program is based on sound learning theory and performance and effectiveness can be measured in a systematic fashion (Salas, Prince et al., 1999).

Few studies have attempted to evaluate the efficacy of CRM training, and this author is yet to see a compelling scientific validation of CRM. In one evaluation the skill areas of communication, assertiveness, mission analysis, and SA were taught to Navy helicopter aircrew as part of CRM training (Salas, Fowlkes, Stout, Milanovich, & Prince, 1999). The training comprised of lectures, video analysis, and practice and feedback through role-play exercises. Performance was measured by the following:

- Trainee reactions questionnaire employed a 5-point Likert scale to measure the aircrews' opinions on the usefulness of the training, and to list ways in which they thought they would use the information provided to them in training;
- Aircrew Coordination Attitudes Questionnaire (ACAQ) which is a 41-item attitude questionnaire (that includes the 25 items from the Cockpit Management Attitudes Questionnaire, which measures attitudes relating to communication and coordination, command responsibility, and recognition of stressor effects);
- A multiple-choice knowledge test to assess knowledge of concepts related to the teamwork skills taught in training; and
- Behavioural assessment using the Targeted Acceptable Responses to Generated Events or Tasks (TARGETs) team performance methodology (discussed in more detail in a later section). Events were included in an evaluation scenario that allowed for specific and observable opportunities for teams to exhibit team coordination behaviours (relating to the four skill areas mentioned above).

Two similar studies were conducted using Navy aircrew, the major difference between the two studies being that the second study employed a repeated measures approach for the behavioural (TARGETs) assessment (Salas, Fowlkes et al., 1999). The scenario required the team to transport troops and cargo from a small ship to an aircraft carrier. The scenario was produced using a PC and Microsoft flight simulator. Performance was videotaped and trained observers evaluated performance according to the TARGETs approach (observers were blinded to training condition). Trainee reactions to CRM were positive in relation to mission accomplishment and flight safety, and training increased the positive attitudes towards teamwork in the cockpit (study 1 only). Trained aircrew also performed significantly better on the knowledge test (related to principles of teamwork). With regard to the TARGETs, trained teams displayed more teamwork behaviours than untrained teams for high workload segments but not lower workload segments. Their studies provide some evidence that CRM training can improve teamwork in experienced aviators, and that the same training can be effective for both pilots and aircrew.

Thompson et al (1999) evaluated the effectiveness of CRM training in MH-53J helicopter crews (twin engine helicopter). Sixteen three-person crews participated in a mission simulation during their annual week-long refresher training. The mission simulation involved two other helicopter simulations and associated ground controllers. A CRM worksheet was used by observers to rate team performance on a scale of 1 to 5 for the

seven dimensions of SA, crew coordination, command control and communication, decision making, task management, mission evaluation, and tactics employment. Each crew member was given a rating for each dimension, and then an overall crew rating was provided. Mission performance was also evaluated by observers. Thirty-one mission performance elements were identified *a priori* and a rating scale of 1 to 5 was used to rate team performance for each element. Overall CRM and mission performance were highly correlated (0.84), and mission planning (and time spent planning) were significantly correlated with mission performance. These behaviours that are associated with improved mission performance should form the basis for mission training (Thompson et al., 1999).

While the studies discussed above suggest that CRM training leads to improvements in various dimensions of teamwork, they are not rigorous scientific evaluations of CRM and the occurrence of human error and accidents.

3.2.2 Cross Training

Cross training is a relatively new strategy in team training which has the goal of providing exposure to and practice with the tasks, roles, and responsibilities of the other team members (Salas & Cannon-Bowers, 2000). It is based on the theory of the shared mental model, in that team members need shared knowledge structures (mental models) to be able to generate common predictions and expectations, which thus allows teamwork to occur without overt communication (Cannon-Bowers et al., 1993). The development of such knowledge improves team members' ability to predict, anticipate, and coordinate their activities by increasing the accuracy of their knowledge about the roles, tasks, and information needs of their team-mates (Volpe, Cannon-Bowers, Salas, & Spector, 1996). Debrief sessions are designed to involve team members in the interpretation of critical events and to help create shared knowledge of team-mates' expectations. It has been hypothesised that teamwork that develops compatible mental models should lead to improved team performance (Salas & Cannon-Bowers, 2000).

Kleinman and Serfaty (1989) suggested that that some teams were able to maintain high levels of performance in high workload conditions because they were able to compensate for their inability to communicate through the exercising of a common understanding of the situation. This knowledge allowed the team members to use an implicit coordination strategy in which the need for overt communication is minimised. This strategy also emphasises the ability of effective team members to anticipate the actions of other team members thereby reducing the need for overt communication.

The implicit coordination that is believed to allow teams to function effectively in high workload environments involves the use of shared mental models. Shared mental models, in this context, contain a common model of the tactical situation among team members and mutual models of other team-member functions. It is the latter type of model that allows team members to pre-empt the behaviour of others in the team and to coordinate actions in the absence of explicit communication.

Entin and Serfaty (1999) used the Team Adaptation and Coordination Training (TACT) procedure to measure the effects of stress on team coordination strategies. TACT involves lecture-type instruction, observation via video of correct and incorrect strategies, and practice via training scenarios. An additional procedure involved periodic situation-assessments from the instructor (TACT+). Six teams of five naval officers performed in either control, TACT, or TACT+ conditions, in both high and low stress conditions. High workload was induced via a 50% increase in the number of targets in the 25-30 minute scenario. The teams had to correctly infer the identity and intentions of those targets. Trained naval officers rated team performance using the Team Anti-Air Warfare (AAW) scale, which consists of 12 items that assess AAW performance and 15 items that assess teamwork dimensions (team orientation, communication, behaviour, monitoring behaviour, feedback behaviour, back-up behaviour, and coordination behaviour). Psychologists coded verbal behaviour during the sessions using a matrix that coded the type and content of messages, and the person(s) to whom the message was directed. Workload was measured using the NASA-TLX measure of subjective workload. Pre and post-training tests showed that adaptation training via TACT and TACT+ significantly increased process measures of teamwork, and the level of teamwork was higher than for the control group. The adaptation training, particularly TACT+, allowed teams to manage the effects of high workload. These results combined suggest that team adaptation training improved teamwork and coordination strategies, and that teams can be trained to recognise the signs of increasing workload. Unlike cross-training, this training is sufficient to maintain performance under stress.

3.2.3 Team Self-Correction Training

Basically this form of training dictates that effective teams will review events, correct errors, discuss strategies, and plan for future events. It attempts to formalise this natural tendency in effective teams. Knowledge-based (mental models), skill-based, and attitude-based competencies are developed without a formal instructor. Principles for this form of training are outlined elsewhere (Salas & Cannon-Bowers, 2000).

Team Dimensional Training (TDT) incorporates guided team self-correction to develop key knowledge and skills amongst team members (Smith-Jentsch, Zeisig, Acton, & McPherson, 1998). It involves a facilitator who establishes a positive environment, keeps the team discussion focussed, encourages and reinforces active participation, models effective feedback, and coaches team members in stating their feedback in a constructive manner. It is designed such that teams can gain the greatest value from self-correction. That is, it can be used to improve team performance by encouraging various types of shared knowledge, and consequently it aims to develop shared mental models (Smith-Jentsch, Zeisig et al., 1998).

3.3 Approaches to team training in complex high-technology environments

There is a vast literature concerning the development of training systems for complex and technology rich environments. The systems approach identifies different subsystems in the developments of training and how they relate to each other, and the functions they perform. Instructional Systems Development (ISD) methods are logical in nature in that the components are specified in terms of the prescribed goals. ISD methods are useful in that the development of training is expressed as a series of goals. While identifying what the goals are, these methods are not psychological in nature and do not specify how the goals might be achieved. This latter process is considerably more difficult than specifying the goals to be achieved (Patrick, 1992). There are literally hundreds of different ISD methods. All tend to involve broadly similar stages. Further detail of an ISD process for complex environments is presented below.

3.3.1 The Instructional Systems Development Process

Following is brief discussion of some more specific tools for team training associated with high technology environments. While not specifically related to teams, Williams & Pearce (1999) outline the ISD process for Virtual Environment (VE) training technologies.

<u>Needs Analysis:</u> A Needs Analysis is required when there is a change to operational procedures, the development of new processes, the desire to cut costs, and so on. Basically this process involves identifying the tasks involved to perform the activity. An example provided by Williams & Pearce (1999) concerns the US Navy and a decision to downsize and seek alternative and lower cost methods for training. It was decided that full mission simulation-based training was a potential means to reduce training costs. So the tasks involved in ship handling performed as part of the job were identified to determine alternative training technologies and techniques that might be available. It is then necessary to determine which objectives critical to meeting the organisational objectives are involved in the current job (i.e., how important is the job relative to the organisational objectives). A major goal of the Needs Analysis is to specify the job requirements and/or objectives.

In fact, when the instructor station is developed, even conceptually, to a given point an ISD or training needs analysis can be done to identify the tasks to performed by the instructor, the expected sequence of tasks, potential conflicts between instructional features, the areas in which the instructors will need training, and the nature of coordination between instructors when more than one instructor is involved (Cream, Eggemeier, & Klein, 1978). Furthermore, each feature of the instructor station should be evaluated against a number of dimensions: demands placed upon instructor time and attention; anticipated frequency of use of the instructional feature; computational demands; location of the instructor; and actual training support provided by the feature (Cream et al., 1978). As with individual tasks in a training task functional analysis, each of the instructional features should also be assessed by SMEs along the dimensions of

criticality (determination of the training implications of not including that feature), frequency of performance (the expected use of the feature), and difficulty of performance (difficulty of operation of the feature).

Quite surprisingly, consideration of the training requirements for instructor stations are infrequently discussed in the team training literature. Clearly however the role of the instructor is critical in the success of a team-training program. There are many stages of the training system development process that can influence the instructor station requirements for team training. For example, determination of the performance measurement capabilities can influence design of the instructor station because the instructor must be able to observe and collect the required performance data (Cream et al., 1978). The role of the instructor is one primarily of instruction rather than evaluation, and the instructor station should support that performance of a number of instructor functions: controlling and setting up tasks; measuring trainee performance on the tasks; displaying and recording performance measurements in a useful format; and presenting the measurements and other instructional communications as feedback to the trainees (Cream et al., 1978).

Task Analysis: Having specified the job objectives from the needs analysis, the next step of the ISD process is to identify the tasks that must be performed by teams or individuals in order to meet the job objectives, which is achieved using task analysis. Each of the job objectives must be defined in terms of the specific functions which must be performed by each person. Task analysis therefore involves breaking down each job objective into the component tasks required to achieve these objectives. Typically the task analysis will involve a person observing an individual performing the job activities necessary to achieve the job objectives.

The activities to be performed for each particular task are analysed in terms of the stimuli in the task environment and the responses to those stimuli. The analyst can then infer the skills and knowledge required to perform those tasks. The input characteristics must be set beforehand by the analyst. That is, the baseline level of skills and knowledge possessed by the operator (i.e., degree of existing expertise, knowledge, and skill). In addition, the analyst would also specify the fundamental abilities, such as visual and auditory requirements, physical requirements, etc, related to successful completion of the job tasks.

Finally, having documented the skills, knowledge, and abilities necessary to perform the task, the analyst should then specify indexes that can be used to measure performance on the various tasks. Consequently the analyst, in consultation with experts, can derive an agreed-upon level of performance that would be indicative of someone who had learned the tasks with a level of mastery. These performance measures can be used to measure the progress of a trainee through a training program. The outputs from task analysis are clearly critical to the design of a training system.

Relatively little work has focussed on task analysis at the team level. As such, designers of team-training programs have often been required to decide which tasks should be trained

individually and which as a team without systematic procedures or guidance. There needs to be a clear distinction between individual and team tasks for team training to be fully effective. There have been few attempts to develop a team task analysis tool, although Cannon-Bowers and colleagues have developed a methodology for specifying the coordination demands of complex team tasks. This methodology has been useful in the aviation domain for specifying tasks that require coordination and team training objectives. It extends upon traditional task analysis by asking experts to provide information about task interdependency (Salas & Cannon-Bowers, 2000).

Curriculum Development: The outputs from the task analysis are then used to develop the lessons or scenarios, the objectives of each scenario, and the critical levels of performance that must be achieved.

Selection of a Delivery Device and Media: Basically system designers must analyse the curriculum material and determine the most appropriate method of presentation for the training program. Cost can be a significant issue here, and hence cost-benefit analyses can be conducted at this stage.

Training Program Conduct and Evaluation: This section briefly discusses how to examine whether a training program is effective. That is, conduct an experiment in which a control group does not receive training and an experimental group that does receive the training, and examine differences in pre and post test performance. If the training program is effective then significant differences between pre and post test performance should be found (as a function of the training program).

Feedback Cycle: This relates to consideration of the evaluation and the costs of training versus the improved performance.

It is important to bear in mind that the emergence of new technologies does not justify their use for training unless the effectiveness of training can be assured.

3.3.2 Event-Based Approach to Training (EBAT)

A related but quite distinct approach to training design is EBAT. This technique has been used widely in recent years, particularly in military environments. It is based on the premise that learning is a cognitive and behavioural process. Effective performance often requires a range of competencies across knowledge, skills, and attitudes, as discussed in the previous section. Effective performance can become more challenging when few procedures exist or when more than one approach can be used to execute the task. Learning must therefore focus on cognitive and behavioural processes, and the training systems must provide an environment that supports the acquisition of the competencies required to achieve task performance (Oser, Cannon-Bowers, Salas, & Dwyer, 1999; Salas, Oser, Cannon-Bowers, & Daskarolis-Kring, 2002).

A systematic approach to learning will facilitate skill acquisition & retention. Complex skill acquisition requires a systematic approach to learning that is based on sound learning and measurement methods, strategies, and tools. This systematic approach must contain specific pre-planned instances where the trainees demonstrate their ability to perform the tasks and receive feedback on critical competencies. These instances must be believable and transparent to the trainee otherwise the task may not be performed realistically (Oser et al., 1999).

Training for complex environments requires a scenario-based approach. Effective learning environments need to facilitate the ability to develop and maintain competencies (i.e., knowledge, skills, and attitudes) required to perform the task. Scenario-based (or event-based) training can ensure that such learning occurs by tightly linking critical tasks, objectives, scenario design and execution, measurement, and feedback (Dwyer, Oser, Salas, & Fowlkes, 1999; Oser et al., 1999).

The tactical decision-making involved in distributed training scenarios necessitates that events (cues) are embedded in the task at different time intervals. Sets of events become the basis for assessment because not all aspects of performance can be measured during an exercise. These events are there to provide opportunities for the required team-based competencies to be exhibited and subsequently measured and used for providing feedback (Salas & Cannon-Bowers, 2000).

While this form of training has been used in aviation settings, tactical team decision-making environments, and distributed training scenarios, it has great potential for further military applications (e.g., combat crews can be trained and systematically exposed to events that represent the major types of threat situations). Variations in simulation fidelity can be used to allow crews to practice critical decision-making and coordination skills in response to particular (important) cues. The provision of prompt and meaningful feedback to physically separated trainees is a focus of current/future research (Salas & Cannon-Bowers, 2000).

EBAT is used to design simulation-based exercises, and these techniques create training opportunities by systematically identifying and introducing events within training exercises that provide known opportunities to observe specific behaviours of interest (Fowlkes, Dwyer, Oser, & Salas, 1998). EBAT has been used widely in the team training in complex environments literature, such as for evaluating tactical decision-making performance of AAW CIC teams (Johnston et al., 1997), and for aircrew coordination training (Fowlkes et al., (1994).

In EBAT, the training exercise is the curriculum, and the primary goal is to provide trainees with opportunities to develop critical competencies by receiving practice in simulated environments that are representative of actual operational conditions, and receiving feedback linked to specific events that occur during training. EBAT highlights linkages between all phases of training (design, measurement, feedback) and so can

inform the design of system infrastructures (Oser et al., 1999). The components of EBAT are described in more detail below.

The EBAT framework highlights linkages between all phases of training. The phases will be discussed briefly in the following sections. EBAT begins with the specification of the training objectives, including the critical tasks that should be performed, the conditions under which those tasks should be performed, and the standards of acceptable performance (Dwyer et al., 1999). The key phases of EBAT are discussed below.

1. Skill Inventory/Historical Performance Data: Scenarios should be based upon the training audience's inventory of skills and archived historical performance. This process should highlight areas of skill that need to be improved, rather than maintained, and should result in a more focussed and relevant training program (Oser et al., 1999).

2. Task Lists: Specific tasks can be identified to inform scenario design based upon the skill inventory and historical performance data. Ideally an organisation would have detailed lists of tasks, techniques, and approaches, that must be performed for effective operation of the complex system.

3. Learning Objectives/Competencies: Objectives and related competencies associated with the skill inventories, historical data, and task lists, can then be specified. Objectives can be task specific or refer to general competencies across tasks (e.g., SA, decision-making). The learning objectives should be specified in such a way as to enable objective and subjective assessment about whether they were achieved (Oser et al., 1999).

The learning objectives specify the training areas on which to focus. They represent components of behaviour that may have been deficient in the past, difficult to perform, etc, and so must be practiced in order to maintain proficiency (Dwyer et al., 1999).

4. Scenario Events/Scripts: A key distinguishing feature of EBAT is the scenario events which provide specific opportunities for the training audience to practice critical tasks and competencies associated with the learning objectives. The events allow the trainees to demonstrate their strengths and weaknesses for the purposes of performance measurement and feedback. The Master Scenario Event List (MSEL) is an organised structure that lists all of the events that are planned for a particular scenario, and contains timing of events, relationships between events and objectives, etc (Oser et al., 1999).

EBAT emphasises the requirement for events to be driven by training objectives. Another aspect of these events is that sequential dependencies are minimised, or in other words, much effort is devoted to ensuring that the ability to respond to a given event is independent of performance on the previous event (Fowlkes et al., 1994).

To ensure task consistency across teams, scenario scripts are developed that detail when events should occur and the communications that should occur from other personnel as

part of the scenario. These scripts also allow the instructor to anticipate events and to evaluate performance based on the behaviours of interest (Fowlkes et al., 1994).

The trigger events are identified for each learning objective, and should create specific opportunities for the trainees to demonstrate their ability to perform the tasks associated with the learning objectives (Dwyer et al., 1999). These events also provide controlled situations in which performance can be measured. The use of controlled trigger events is especially critical for non-routine tasks when the opportunity for practice may not arise unless intentionally introduced. An example used by Dwyer et al. (1999) is a learning objective that focuses on the proper execution of procedures for switching to a back-up communications plan.

<u>5. Performance Measures/Standards:</u> The development of performance measures and tools required for data collection associated with the trigger events is the next step in EBAT. Data should also be collected on both outcomes and processes (Oser et al., 1999).

Multiple events of varying difficultly should be specified for each learning objective, and introduced throughout the training exercise, to allow the development of a training profile of how performance is going for each objective across a number of conditions (Dwyer et al., 1999). There is considerable discussion about performance measurement in a later section (Section 4).

<u>6. Performance Diagnosis:</u> Basically this states that the diagnosis of data is a critical stage of the training process. The diagnosis can be via automated, semi-automated, or instructor-led feedback.

<u>7. Feedback and Debrief:</u> Feedback is linked to the performance measures, which is linked to the trigger events and the learning objectives – again emphasising how EBAT links the critical scenario components. Feedback should relate to both process and outcome (Oser et al., 1999). The EBAT approach emphasises the need for data to be presented in a format that supports feedback to trainees (Dwyer et al., 1999).

In summary, a training objective is identified, from which learning objective(s) can be defined. Ideally more than one trigger event will be used to assess performance for each of the learning objectives, and performance measures are used for feedback in the after-action review (Dwyer et al., 1999). Table 2 below illustrates the link between training objective and performance for a close air support task.

Table 2: An example to illustrate the link between training objectives and performance measurement using EBAT (adapted from Dwyer et al., 1999).

Training Objective	Learning Objective	Trigger Event	Performance Measures	Feedback
- Control close air support attack task - Daytime operations - No errors	- Demonstrate behaviours required to adapt to loss of communication during air attack	- Introduce primary communication failure at specific time in exercise	- Pilots notified of communication loss - Consideration of other resources - Back-up plan implemented	- Replay event - Provide data - Discuss what occurred, why, and how to remedy

Several tools can be used to measure the aspects of performance identified above, including TARGETs. Measures of performance are discussed in detail in a later section.

It is claimed that there are at least two ways that EBAT can be used for cognitive learning and the development of knowledge structures. Firstly, an EBAT that is driven by CTA can expose trainees to known cue situations for comparison. An example provided by Fowlkes et al (1994) is that a controller can learn to distinguish between situations that require a call for descriptive information (e.g., bogey capping, high) versus those that require a call for directive information (e.g., hornet 21, break right). Hence, it is claimed, the development of schema can be fostered through careful design of training scenarios. Secondly, EBAT can also be used to measure trainees procedural (how to) knowledge, and thus can be used in the assessment of cognitive skills (Fowlkes et al., 1994).

3.3.2.1 *How does EBAT differ from other frameworks for training design?*

Unlike approaches such as the ISD approach, EBAT specifically focuses on training where the trainee is immersed in simulated operational environments. This has allowed EBAT to address the unique aspects of training in simulated environments where the scenario is the curriculum. EBAT has also been applied extensively in training situations that incorporate simulation. Finally, EBAT results in quantifiable improvements involving simulation and both individual and team performance of complex tasks (Oser et al., 1999).

Fowlkes et al (1998) summarise the key training and measurement benefits of the EBAT. The event-based scenario design means that the training exercises are linked directly with the training requirements. This is the case because the task lists, required competencies, etc, feed directly into the design of the specific scenarios. The level of control over scenario content allows for reliable observation of the targeted competencies and accurate assessment of those competencies. Similarly, the event-based observation allows for standardisation of observations and control over task content. Finally, EBAT reduces instructor workload as the requirements for real-time observations are reduced. EBAT prompts specific behaviours to occur and thus allows them to be learnt and reinforced.

3.3.2.2 *Specific Event-Based Learning Methods*

An example of a widely used EBAT method is the TARGETs, which involves in-depth analyses of specific simulator scenarios that are used to evaluate training effectiveness (Fowlkes et al., 1994). TARGETS was developed to evaluate the behavioural component of a Navy skill-based aircrew coordination program. Detailed examples using the TARGETs methodology are discussed in the next section of the report concerned with the measurement of team performance.

A second method will be discussed in more detail here. The TADMUS program (Tactical Decision Making Under Stress) has been used as the foundation for an event-based learning method for designing a continuous training cycle (Stretton et al., 1999). This six year program of research was instigated after an incident in 1988 involving the shooting down of an Iranian airliner by a US Navy vessel. The goal of TADMUS was to improve methods to train tactical decision making in teams and individuals in stressful situations such that proficiency is enhanced (Cannon-Bowers & Salas, 1998). This was done within the context of a ship's Combat Information Centre (CIC) environment.

The major theoretical perspectives that were drawn upon in the development of the TADMUS program were naturalistic decision-making and shared mental models (Cannon-Bowers & Salas, 1998). After consideration of theoretical perspectives it was possible to generate a series of hypotheses for training. Some of the training interventions derived from the hypotheses included EBAT, TACT, team leader training, and cross training (Cannon-Bowers & Salas, 1998). Team leader training focussed on improving the feedback skills of the people who led the team's prebrief and debrief associated with each exercise. It included lectures, demonstrations of effective and ineffective briefings, and roleplays (Smith-Jentsch, Johnston, & Payne, 1998).

After an analysis of over 50 videotaped teams in the CIC environment, SMEs identified a number of teamwork behaviours that seemed to differentiate high and low performing teams (Johnston et al., 1997). These behaviours were grouped under the dimensions of SA, communication, supporting behaviour, and team initiative or leadership. The Anti-Air Teamwork Observation Measure (ATOM) was subsequently developed, and records observations of specific behaviours associated with these dimensions. Performance measurement techniques are discussed in the next section of the report.

3.3.3 Summary

Only the more prominent and relevant forms of team training and instructional strategies have been reviewed here. While the EBAT approach to team training in complex high technology environments has been widely used in the military domain, there may also be a role for other forms of team training, such as team coordination training and cross training. The extent to which these other forms of team training might be involved in distributed training would depend largely on the extent to which the critical team processes (SA, mental models, etc) are adequately covered in the EBAT approach. The

following section discusses literature concerning the measurement of these team processes.

4. Measurement of team processes

There are several means by which to measure the effectiveness of a training simulation. These methods include utility evaluations (seeking opinions of effectiveness from relevant sources), in-simulator learning (evaluating improvements in simulator performance), and transfer of training studies (examining if and how simulation training affects subsequent performance) (Bell & Waag, 1998). Across many fields including medical, nuclear power plant, commercial aviation, and military aviation, there are few robust empirical evaluations of the effectiveness of simulator-based training (Bell & Waag, 1998; Thurman & Dunlap, 1999). The majority of this section is therefore concerned with performance before, during, and after a training program. Few transfer of training studies have been conducted, and are discussed towards to the end of this section.

Measurement of performance is critical for effective learning. Performance measurement should include collection of data pertaining to the outcomes (whether the right decision was made) and the processes (whether the decision was made correctly). A range of performance measures and systematic assessments of those measures ensure the effective provision of feedback, and subsequent improvements in performance. Performance measurement is therefore critical in ensuring that the training program is having its intended effect, and allows trainers to assess, diagnose, and refine performance (Oser et al., 1999). In the team training scenario the performance measures need to capture the dynamic and multilevel nature of teamwork, which is not a trivial task. Salas and Cannon-Bowers (2000) state that any measures of team performance must have the following features; be theoretically based; assess and diagnose team performance; address team outcomes as well as processes; capture moment-to-moment behaviours, cognitions, attitudes, and strategies; consider multiple levels of analysis; consider multiple methods of measurement; provide a basis for remediation, and; rely on observation by experts.

Dwyer et al (1999) discuss the importance of using both outcome measures and process measures of team performance. With regard to outcome measures, tools have been developed to measure data such as the number of bombs released, the timing of bomb releases, and the percentage of bombs resulting in intended impact. Outcome measures provide information to identify what happened in an exercise and to help to identify areas of trainee difficulty. Process measures focus on behaviours as the exercise unfolds and are used to determine why the difficulties occurred. It is important to measure team processes rather than simple team outcome measures because process measurement is important for providing information that is useful for diagnosing the cause of poor performance (Paris, Salas, & Cannon-Bowers, 1999).

The challenge in measuring team performance is to define good measures of team processes. As Salas et al (1995) review, a number of measurement techniques have been developed for assessing military team performance. These measures, such as the Critical Team Behavior Form (Morgan et al., 1986), the Aircrew Coordination Observation and Evaluation form (Franz et al., 1990), the Teamwork Observation Measure, the Teamwork

Rating Scale (Brannick, Roach, & Salas, 1993), and the Anti-Air Warfare Team Performance Index (Johnston et al., 1997), all involve having expert observers rate the teams, either on-line or via analysis of videotaped performance, according to a predetermined checklist of teamwork behaviours. Discussions following focus on process measures of performance.

Before discussing in detail some of the process measures of team performance, it is necessary to state that it is quite difficult to interpret these findings with a high degree of clarity. As discussed in an earlier section of this report, there are a number of higher-order cognitive processes for teams (e.g., control of attention, shared SA, shared mental model, and metacognition). There are also several core dimensions of teamwork that have been identified in the literature (e.g., communication, team orientation, team leadership, monitoring and awareness of the activities and performance of other team members, feedback, and coordination). The majority of studies that are discussed in the following section appear to use at least one of these teamwork dimensions in order to make inferences about team processes. For example, studies will often measure the dimension of communication in order to make inferences about the team's SA, or measure coordination to make inferences about shared mental models. The difficulty in interpreting the results from previous studies is that each study seems to use different combinations of teamwork dimensions to draw conclusions about team processes. This is apparent via quick inspection of Table 3 which summarises some of the team dimensions and processes that have been examined in the literature. Given the range of teamwork dimensions used in the literature it would seem that there is not solid agreement about the critical teamwork dimensions for optimal team performance.

This next sections (4.1 & 4.2) describe studies that have measured dimensions of teamwork such as: communication; team coordination; team adaptation; information exchange; supporting behaviour; team leadership; assertiveness; decision-making; technical coordination; interpersonal cooperation; team spirit, and; cross-monitoring. The section on Team Knowledge (4.2.1) focuses more on the measurement of Team SA and shared mental models.

Table 3. Summary of some of the studies that have measured teamwork dimensions and processes.

Authors	Team processes and teamwork dimensions	Task	Measurement Tools	Results
Stout, Salas, & Fowlkes (1997)	Team competencies – SA, communication, and assertiveness.	- 2 day team training course for student pilots - flight simulation with trigger events	- Pre and post training attitudes measured using adapted CMAQ - Multiple choice knowledge test - TARGETs, percentage of correct teamwork behaviours (list of observations developed by experts via videotapes of performance)	Training in team competencies of SA, communication, and assertiveness resulted in higher knowledge test scores and improved team performance
Entin & Serfaty (1999)	Teamwork and communication	TACT (adaptation training)	- Team anti-air warfare performance scale (which measures team performance and dimensions of teamwork) - Coding of verbal behaviours by raters (type/content of communications and intended recipients)	TACT improved teamwork and coordination strategies
Dwyer et al. (1999)	Teamwork dimensions communication, coordination, adaptability, and SA.	5 day multi-service distributed exercise for Close Air Support mission	Teamwork Observation Measure, which identifies 69 teamwork behaviours that fall within the four dimensions of teamwork they used.	Teamwork improved but never 'outstanding'
Bowers et al. (1993)	Team coordination (demand)	Coordination ratings of 38 core helicopter tasks by 40 military pilots	The Coordination Demand Questionnaire, which requires a rating of 0 (not needed) to 10 (needed constantly) for the coordination dimensions of communication, SA, decision-making, mission analysis, leadership, adaptability, assertiveness, & total coordination.	- Coordination demands higher during take-off and landing - Non-routine tasks deemed to require greater coordination than routine tasks
Stout et al. (1994)	Team coordination	- Low-fidelity simulation in pairs of undergraduates - Maintain specific altitude and destroy designated targets	- Rating of control skill by experimenter of 1 to 7 (joystick control for pilot, keyboard control for co-pilot) - Rating of 1 to 7 for each person for the dimensions of mission analysis, assertiveness, decision-making, adaptability/flexibility, SA, leadership, & communication - Rating of 1 to 7 for overall mission performance - Number of targets hit	- Holding control skill constant, teams with higher coordination had higher ratings of mission performance - All measures of coordination for pilot positively correlated with mission performance, but only SA, MA, and Flex correlated with no. of targets hit - DM, Flexibility, & SA for co-pilot correlated with mission performance

Table 3 (cont)

Authors	Team processes and teamwork dimensions	Task	Measurement Tools	Results
Annett et al. (2000)	Team communication and coordination	Anti-submarine warfare teams	TARGETs – just over 40 'correct' behaviours identified a priori for 14 trigger events, ratings by observers via video recordings	Only 21% of anticipated team actions were observed. Concerns of SME ratings were raised.
Salas et al. (1999)	Communication, assertiveness, mission analysis, and SA	CRM training program for Navy helicopter aircrew, mission scenario created in Microsoft Flight Simulator	- Aircrew Coordination Attitudes Questionnaire (ACAQ) - Multiple choice knowledge test - Behavioural assessment using TARGETs approach relating to the four identified team processes	Teams receiving CRM hit more targets and displayed more teamwork behaviours.
Thompson et al. (1999)	SA, crew coordination, command control and communication, & decision making.	CRM training program for Navy helicopter aircrew. Crews observed during mission simulation	Individual and crew ratings on the team processes, and ratings of mission performance for 31 mission performance elements	CRM training improved mission performance
Johnston et al. (1997)	SA, communication, supporting behaviour, team initiative, team leadership	Observation of Navy teams in Command Information Centre	Video analysis of performance by SMEs. Behaviours associated with good teams were identified which fell under the five dimensions identified.	Better performing teams displayed great teamwork across these five teamwork dimensions
Volpe (1996)	Technical coordination, interpersonal cooperation, team spirit, team leadership, & communication	Cross training program in two person teams of non-experts performing a simple flight simulation task	Teamwork rated during training by observers using a modified version of the Teamwork Rating Scale. Objective simulator-based measures were also collected (e.g., time taken to shoot first enemy target).	Cross-training increased team coordination and efficiency of communications, and resulted in improvements in objective measures of performance
Salas et al. (1999)	Communication, mission analysis, SA, and assertiveness	Navy helicopter aircrew undergoing CRM training performed a flight simulator task	Performance measured using TARGETs approach and multiple choice knowledge test	Trained aircrew performed significantly better on the knowledge test (related to principles of teamwork). Trained teams displayed more teamwork behaviours than untrained teams (for high workload segments but not lower workload segments).

Table 3 (cont.)

Authors	Team processes and teamwork dimensions	Task	Measurement Tools	Results
Stout, Salas, & Kraiger (1997)	Knowledge structures and shared mental model (communication & assertiveness)	- 1 day training course that aimed to develop SMM in military aviators - 40 min flight sim with trigger events	- Pre and post training attitudes measured using adapted Cockpit Management Attitudes Questionnaire (CMAQ). - Multiple choice knowledge test - Knowledge structures measured using Pathfinder, data from relatedness judgements for pairs of training concepts on scale from 1 to 9 - TARGETs, percentage of targets hit (list of 85 observations developed by experts via videotapes)	Training in team concepts resulted in knowledge structures more similar to domain experts, more positive attitudes to teamwork, and greater teamwork (TARGETs checklist). Trained and control teams did not differ on the multiple choice knowledge test.
Stout et al (1999)	Shared mental model	Low-fidelity helicopter simulator, 40 undergraduates	- Subject ratings of pairs of concepts related to the mission using 7-point scale, and Pathfinder C. - Ratings by experimenters of 7 planning dimensions using 7-point likert scales	Teams that planned better developed greater shared mental models of each others informational requirements
Fowlkes et al. (2000)	Shared mental models	Pilot instructors and students completed surveys after viewing video of helicopter flights	Responses were coded according to declarative, procedural, and strategic mental models.	Instructor responses indicative of strategic model whereas student responses indicative of procedural models.

4.1 Measurement using the TARGETs methodology

As discussed earlier, the TARGETs methodology involves in-depth analyses of specific simulator scenarios that are used to evaluate training effectiveness (see Fowlkes et al., 1994). The TARGETs methodology was developed within the context of the EBAT. It uses a behaviourally focused checklist to record observations of team behavior. SMEs, doctrine, manuals, and standard operating procedures, are used to define anticipated behaviours for specific events a priori. The behaviours are listed in the checklist in the approximate order in which they are likely to occur during the exercise, and are further broken into discrete phases of the mission. During an exercise observers rate each behaviour on the checklist as acceptable, unacceptable, or not observed. In terms of validity, TARGETs checklists have been shown to have good inter-observer reliability (r=0.94) and internal consistency (r=0.81), and have good face validity for observers and participants (Fowlkes et al., 1994). The data can also be used to provide more detailed feedback to trainees than outcome data. The groups of behaviours in the checklist can be divided into functionally related clusters and a percentage of correct behaviours can be calculated (Dwyer et al., 1999). The following studies provide examples of large scale distributed exercises to illustrate the measurement of team behaviour using the TARGETs methodology.

It should be emphasised again that the TARGETs checklists are scenario specific, and are thus based upon anticipated teamwork behaviours for a given training situation. Other checklists such as the Teamwork Observation Measure are scenario independent and based upon generic teamwork behaviours.

<u>Example 1:</u>

Dwyer and colleagues (1999) reported a multiservice distributed training exercise focusing on multiservice close air support (CAS) mission training (case study 2 in the paper). The five-day exercise involved the following forces: the US Army's Mounted Warfare Testbed facility in Fort Knox, which included an Army battalion task force (command staff) and Tactical Air Control Party operated in a simulated Tactical Operations Centre and in command group vehicle simulators; two F-16 simulators at Mesa; a Navy Command simulator in San Diego; and a Marine Corps OV-10 observation aircraft simulator that provided an Airborne Forward Air Control platform. The taskforce fought against a semi-automated computer generated force, and had CAS assets available at certain times during the exercise. Each CAS mission was divided into planning, contact point, and attack phases. The planning phase was the period prior to the commencement of the exercise and involved operational briefings for the days CAS missions. The contact point phase was from when the aircraft commenced their inbound route for a predetermined holding area, and continued while the aircraft orbited this point. The attack phase commenced when the aircraft departed the contact point and concluded when both aircraft left the target area. Each site conducted specific After Action Review (AAR) after each 2.5-3 hour exercise, and a multiservice AAR followed about 1.5 hours after the exercise.

Performance was measured using two observational approaches, TARGETs and the Teamwork Observation Measure (TOM). The TARGET checklist developed for this study was based on 25 training objectives, and contained 69 teamwork behaviours across the planning, contact point, and attack phases. The TOM was developed from the US Navy TADMUS program and included behaviours linked to the four dimensions of teamwork, communication, team coordination, SA, and team adaptability, identified a priori. Each of these dimensions was segmented into key components. For example, communication was divided into correct format, proper terminology, clarity, and acknowledgements. Trainees were also rated on how well they interacted with each other for each dimension using a four point scale ranging from 'needs work' to 'outstanding'. The seven observers were all familiar with CAS doctrine, tactics, techniques, and procedures.

Team performance, as measured on the TARGETs checklist, generally improved during the planning phase across the five days. About 60% of the 37 planning behaviours were successfully completed on day 1, and around 95% on day 5. Some specific areas, such as target selection, establishing airspace coordination areas, control of aircraft, and synchronisation of CAS resources, were particularly low on days 1 and 2 (around 40-50% successful behaviours), but quickly rose to over 90% on days 4 and 5. The TOM data also showed improvements across the five days for all teamwork dimensions (communications, SA, coordination, and adaptability). Performance on none of the dimensions was rated above satisfactory until day 3, which was a point for expansion in the AAR.

During the contact point phase, TARGETs performance improved from around 80% to 95% across days 1 to 5. However, the TOM data never reached a rating of 'very good'. In combination, the TARGETs and TOM data suggest that essentially all of the tasks that should have been performed were performed, however teamwork could have improved. A very similar trend in performance was observed for the attack phase. Inter-rater agreement was on average 83% across the different locations.

While the data provided here are preliminary in the sense that they relate to one case study for a particular group of trainees (and due to limitations relating to sample size and network drop-outs), it is interesting to note that teamwork was only rated as 'very good' in the planning phase, and was never rated as 'outstanding' for any of the four teamwork dimensions at any time during the five day exercise. Clearly it would seem that there is some justification for effort to be directed toward further understanding of the team dimensions of communication, coordination, adaptability, and SA, and how best to train them in distributed environments, as it is assumed that enhancing teamwork could only improve team performance.

Example 2:

The second example of the TARGETs approach being used in a large scale distributed exercise concerns an exercise called RoadRunner '98, which was an exercise conducted by the Air Force Research Laboratory (AFRL) in the United States, and was designed to assess to effectiveness of DMT for aircrew training (Crane, Schiflett, & Oser, 2000). This week-

long exercise involved AWACS simulators, F-16C Multitask Trainers at Mesa, and Boeing Weapons and Tactics Trainers at Kirtland Air-Force Base were operated by F-15 pilots. The exercise also included computer-generated forces which included friendly and enemy fighters, helicopters, ground vehicles, and surface-to-air threats.

The training scenarios were designed to develop specific individual, team, and inter-team skills. A number of missions were flown, including Surface Attack Tactics (SAT) flown on days 2 and 5 of the exercise (SAT 1 and SAT 2). Outcome measures of performance were collected during the SAT missions, including bomb scores (distance from mean point of impact), and number of kills and losses. As in the study discussed in example 1, team process data was collected using the TOM and TARGET approaches. The dimensions of the TOM are shown in Table 4.

During the SAT missions observers rated each of the four dimensions on a scale from dangerous (1) to extraordinary (5). Ratings were provided for each mission phase (brief, prior to push, ingress, combat air patrol formation, intercept engagement, ground target attack, egress, debrief) as well as for the overall mission.

The TARGETs approach is of course scenario specific. In this example scenario-specific team behaviours were identified a priori and given ratings by observers using the five point TOMS scale (e.g., AWACS provides updated picture, fighter provides updated contact report).

Teamwork as measured by the TOM increased from approximately a rating of two to three from the first to the last SAT mission. The changes in each of the four dimensions were similar in many respects across the mission phases, although there were some mission phases that appeared to benefit from the distributed exercise more than others. Ratings for each of the four dimensions (communication, SA, adaptability, coordination) improved from SAT 1 to 2 during the brief, egress, and debrief mission phases, and SA also improved for other phases of the mission. The TARGETs data, by virtue of the fact that it is scenario specific, provided further detail about the change in teamwork behaviours from SAT 1 to 2 across each of the mission phases.

This is a significant study in the area of distributed training, and only some of the details were presented here as they related to the measurement of teamwork. AFRL is continuing to conduct research developing and evaluating instruments to measure team processes (Crane, Robbins, & Bennett, 2001).

Table 4. Dimensions and key factors for the TOM (adapted from Crane et al. 2000).

Dimension	Definition
COMMUNICATION	Exchange of information between two or more team members
Information exchange	Clear, concise exchange of information between elements of the team
Information clarification	Detection of inaccurate or incomplete information and taking corrective action
Information cadence	Timing, rhythm, and flow of information
Information format	Terminology and order of the information
SITUATION AWARENESS	Exchange of information to develop and maintain an accurate perception of the operating environment
Maintaining overall mission view	Interactions involving mission goals and how situational factors affect mission goals
Monitoring mission deviations	Interactions related to detection and communication of changes in environment that may affect mission the plan
Monitoring mission progress	Interactions related to current location and status of mission assets
Understanding current mission state	Interactions that demonstrate the teams shared understanding of mission status
Assessing future mission states	Interactions related to potential modification of mission plan
ADAPTABILITY/FLEXIBILTY	Exchange of information related to modification of plan
Maintaining pre-briefed plan	Interactions demonstrating that the team will not modify its existing plan
Changing to a pre-briefed alternate plan	Interactions demonstrating that the team will be modifying its current plan to a previously briefed alternate plan
Changing to a non-briefed plan	Interactions demonstrating that the team will modify its current plan to a plan not previously briefed
CREW COORDINATION	Exchange of information related to team synchronisation
Providing information in advance	Interactions related to anticipations of other team members' needs and unprompted provision of information
Providing back-up when required	Interactions related to team members recognising the need for and providing assistance
Maintaining contracts	Interactions related to team member implicit interactions agreed upon during the mission brief

4.2 Other studies of team process measurement

Team processes were evaluated in Naval command teams as part of the TADMUS research program using the Anti-Air Teamwork Observation Measure (ATOM). The processes evaluated were those that contribute to performance outcomes at key scenario events (Smith-Jentsch, Johnston et al., 1998). Raters evaluated the teams on 11 teamwork behaviours, which were encompassed by four teamwork dimensions, and ratings were based on notes that were taken during the exercise using the ATOM worksheet. At the completion of the exercise, overall ratings were provided for each of the dimensions on the 5-point Likert scale. The four dimensions are shown in Table 5.

Table 5: The four ATOM dimensions of teamwork and definitions (adapted from Smith-Jentsch et al, 1998, p. 71)

Teamwork dimension	Definition
Information Exchange	Seeking information from all available sources Passing information to appropriate people without being prompted Providing situation updates
Communication	Using correct and concise phraseology Providing complete reports Making audible and ungarbled communications
Supporting behaviour	Correcting team errors Providing/requesting assistance when needed
Team leadership	Providing guidance or suggestions to other team members Stating clear individual and team priorities

It is important to note that these four dimensions were refined from an original list of seven. This was done through extensive consultation with SMEs who expressed concerns with some of the original dimensions, mostly in terms of ambiguity. Dimensions that required the raters to infer a state of mind (e.g., SA) were found to be less reliable that those based on observation of overt behavior, such as the final four dimensions in Table 5 (Smith-Jentsch, Johnston et al., 1998). A factor analysis of 283 ratings of the 11 targeted behaviours revealed the inter-rater reliabilities ranged from 0.82 for team leadership to 0.91 for communication.

These four dimensions of teamwork in the ATOM were differentially sensitive to different forms of training. For example, the team leadership training was found to promote information exchange, supporting behaviour, and team leadership. It did not significantly improve communication compared to control teams, which reflects the emphasis of this form of training. Different methods of training can therefore be selected to emphasize particular dimensions of teamwork (Smith-Jentsch, Johnston et al., 1998).

While research has shown that communication and coordination are related to team effectiveness, there has been little work in validating these concepts. Some research has focused on the construct validity of measures of teamwork (Brannick, Prince, Prince, &

Salas, 1995; Brannick et al., 1993). Through a literature review, critical incident techniques, and rating procedures, Brannick and colleagues defined dimensions for aircrew coordination (assertiveness, decision-making/mission analysis, adaptability/flexibility, SA, leadership, and communication). A checklist was then developed (placing specific behaviours into the above dimensions) to evaluate team proficiency (via paired expert ratings of simulator performance of two person military aircrew teams). They state that their results indicate that the evaluations provided by the judges were psychometrically sound, and that the dimensions chosen were important for team effectiveness (particularly assertiveness, decision making, and communication). However regarding convergent validity, it may be necessary to use multiple scenarios in order to assess team skills because teams may not be consistent across scenarios (Brannick et al., 1995).

In further examinations of team processes, Volpe et al. (1996) used team processes to evaluate the effectiveness of a cross training program in two person teams of non-experts performing a simple flight simulation task. Measures recorded included teamwork process ratings, task performance ratings, and communication frequencies. Task performance was rated by experimenters during the sessions, and could be revised after reviewing video and audio tapes of the sessions (which were also used to record communication frequencies and to generate team process scores).

A modified version of the Teamwork Rating Scale (TRS) formed the basis for the team process ratings (Brannick et al., 1993). The team process dimensions that were selected from the TRS were technical coordination, interpersonal cooperation, team spirit, and cross-monitoring, as these were the dimensions targeted in the training program. An overall team process rating was achieved by summing the individual dimension scores (as there was no evidence that different weighting should be applied) (Volpe et al., 1996). Communication was assessed by the frequency and pattern of inter-member communication factors believed to be relevant to team functioning, which was collected using a communication content scheme. The content of each message was categorized as requesting information, volunteering information, indicating agreement or compliance , task irrelevant remarks, and acknowledgements (based on aircrew communication instrument developed by Krumm & Farina (1962, as cited in Volpe, 1996). Task performance was measured using five objective measures from the simulation: the time it took the team to shoot down the first enemy target; the number of times the enemy was able to lock the team's aircraft with its radar (indicating poor team positioning); the number of times the team's aircraft had the enemy in range; the number of times the team had its radar locked on the enemy; and the total number of enemy aircraft destroyed by the team (Volpe et al., 1996). These measures are task dependent and objective indices of team performance, and are reasonable correlated and directly related to the team mission (as described in a team task analysis) (Brannick et al., 1993). Subjective ratings of overall team quality and technical competency were also made by blinded observers.

Volpe and colleagues (Volpe et al., 1996) were able to demonstrate that cross-training did facilitate team processes, as measured by their selected dimensions. That is, an understanding of the duties of fellow team members increases team members ability to

effectively coordinate their individual activities with those of other team members. Cross-trained teams were also found to generally use more efficient communications. Finally, cross-trained teams were more effective in the performance of the team task as measured by the abovementioned five objective measures of simulator performance. While cross-training was not found to be of any benefit in situations of high workload, cross training did benefit three-person Navy command and control teams in high workload (Cannon-Bowers, Salas, Blickensderfer, & Bowers, 1998). Volpe et al. (1996) concluded by stating that this form of training would be impractical and expensive for highly complex and technical teams, however it has been mentioned in some detail here to highlight approaches to the measurement of team processes and performance.

In an earlier attempt to capture the coordination demands of core helicopter tasks, Bowers et al. (1993) developed The Coordination Demand Questionnaire (CDQ), which requires a rating of 0 (not needed) to 10 (needed constantly) for the coordination dimensions of communication, SA, decision-making, mission analysis, leadership, adaptability, assertiveness, & total coordination. Military pilots were asked to rate the extent to which each of the eight measures of coordination were required to achieve maximum performance for each of the specific tasks. They found that coordination demands were higher during take-off and landing than during steady flight, and that non-routine tasks were deemed to require greater coordination than routine tasks. Data from the CDQ could potentially be used in training scenario design to identify critical teamwork processes for each specific task, and could help in the training of instructors in the identification of specific skills that comprise team coordination (Bowers et al., 1993).

Research has failed to provide a comprehensive understanding of the nature of effective team processes. Even the research on crew coordination is equivocal and offers few useful directions for training. For instance, the research is equivocal about whether teams who use more communications will necessarily perform better or more efficiently (Bowers, Jentsch, Salas, & Braun, 1998). Rather than focusing on the number of communications, some researchers have examined sequential patterns amongst team members, and found that good crews demonstrated very consistent speech in terms of the sequence of speakers and the content of communications (Kanki & Palmer, 1993). In similar research, Bowers et al. (1998) used a common eight-category communication approach to analyse communications of licenced pilots performing a simple flight simulation. They also found that sequences of communications, rather than the number of communications, is important for training good team performance.

4.2.1 Team knowledge

The measurement of team knowledge is critical in the understanding of team cognition and its relation to team performance and the subsequent design of training programs (Cooke, Salas, Cannon-Bowers, & Stout, 2000). For instance, team SA at a particular point in time is thought to be influenced by the knowledge that the team possesses (Stout, Cannon-Bowers, & Salas, 1996). For these reasons it is important to consider the measurement of team knowledge in detail.

Team knowledge is also referred to as shared knowledge, shared mental models, or shared cognition. This knowledge is believed to help teams coordinate implicitly when explicit communications are hampered (Cooke et al., 2000). As stated already, shared mental models provide mutual expectations that allow teams to coordinate and predict behaviours and needs of other team members (Cannon-Bowers et al., 1993).

The majority of measures of team knowledge rely upon the elicitation of knowledge from individuals, and then combining the individual results to generate the collective knowledge of the team. While related to team performance, calculation of team knowledge in this way does not consider the influences of team processes such as communication, SA, etc, that transform collective knowledge into effective knowledge (Cooke, Kiekel, & Helm, 2001).

As discussed in section 2.2, team knowledge can be defined as comprising of the team mental model and team situation model Cooke et al. (2000). Team knowledge is viewed as one of the team processes, along with team decision-making, metacognition, and team SA, that fall under the umbrella of team cognition. Recapping briefly, Cooke et al. (2000) define two types of team knowledge.

The first type of team knowledge is the team mental model, which refers to:

- Knowledge content that is relevant to teamwork and taskwork. Teamwork knowledge can include knowledge of team member roles and responsibilities, and knowledge of their knowledge, skills, and attitudes. Taskwork knowledge can include knowledge such as cue-strategy associations, and knowledge of task procedures and typical strategies;
- Knowledge that is believed to be acquired through formal training, team discussions, and experience;
- Knowledge that is thought to be long lasting knowledge;
- Knowledge associated with the team mental model can be declarative (i.e., factual), procedural, or strategic; and
- Knowledge that provides a collective knowledge base for the team during task performance.

The second type of team knowledge is the team situation model, which reflects the teams collective understanding of the specific situation:

- Unlike the team mental model, this knowledge is acquired during actual team performance;
- This knowledge is acquired at the individual level and reflects a specific understanding of the current task situation (and is thus in a constant state of flux);
- This knowledge guides the team in assessing cues in a situation, determining available strategies, predicting team member behaviour, and selecting appropriate actions. As such, the degree of coordination of team behaviour is dependant upon the team situation model.

In essence team knowledge encompasses task and team-related knowledge held by team members and the collective understanding of the situation. Measuring team knowledge is not however a simple matter of measuring everything that each team member knows. Each team member performs independent and interdependent roles in the team. Within a specific task environment, the measurement of knowledge required by interdependent team members and the distribution of that knowledge across team members should be measured (Cooke et al., 2000).

Team knowledge has predominantly been measured using a collective approach, that is, team knowledge is elicited at an individual level and aggregated across team members to reflect team knowledge. Clearly then the collective approach targets the knowledge of individual team members. This knowledge, combined with team process behaviours, leads to team knowledge. The collective approach therefore undervalues the importance of team processes. The holistic approach describes team knowledge as more than knowledge that is internal or external to team members, but the consequence of numerous interactions within the sociotechnical system (Hutchins, 1991). Few holistic approaches, which would involve interviewing the team as a whole, have been documented (Cooke et al., 2000). Some of the collective knowledge elicitation methods include observations (written, audio, video), interviews (unstructured & structured), and surveys. These methods have been used to elicit knowledge from individuals, which is then aggregated to form a picture of the team knowledge.

The majority of these measures have been directed toward the measurement of the team mental model, that is, knowledge that is more stable and less situation-dependent. These measures also tend not to interfere with task performance as data is usually recorded offline (e.g., via interview). The literature suggests that team mental models do not change rapidly over time, and so would not vary substantially in the time that it takes to elicit knowledge via interviews and surveys. In contrast the measurement of team situation models is more difficult as this knowledge is dynamic. Techniques such as Situation Awareness Global Assessment Scale (SAGAT) have been used to measure individual SA, but are highly specific and not likely to provide the in-depth type of interview data that is needed (Cooke et al., 2000). There is clearly a need for further empirical evidence to verify that team knowledge and other constructs are critical for effective team performance (Cooke et al., 2000; Langan-Fox et al., 2000). The measurement of shared mental models and team SA are discussed in the following sections.

4.2.1.1 Shared mental models

Investigations of shared mental models have tended to focus on team knowledge and coordination. Stout, Salas, and Fowlkes (1997) examined the effects of one day of training team skills on the knowledge structures of military aviators. The training was a newly developed team-training program, and its content was based on a task analysis of teamwork behaviours and skills (Prince & Salas, 1993). It included lectures and demonstrations of two critical concepts of teamwork (communication and assertiveness). Knowledge structures were measured using the Pathfinder technique, which involves

collecting relatedness judgments (28 paired comparison judgments) of eight concepts covered during the training. Trainees made judgments on a nine-point scale, and the Pathfinder technique was used to calculate the similarity of trainee knowledge structures with those of domain experts. Stout et al. (1997) found that the knowledge structures of aviators who received training were significantly more similar to those of domain experts than aviators who did not receive the training. Trainees and controls did not differ significantly in their multiple-choice knowledge test scores.

A similar study was also conducted by Stout, Salas, and Kraiger (1997). In this study the team training was two days duration and included training for situation awareness as well as for the dimensions of communication and assertiveness (each had defined subsets of generic behaviours). As above a flight simulation was devised specifically to concentrate on the abovementioned team concepts, and the TARGETs methodology was again used to measure team processes. Also as above it was found that team training provided the trainees with the necessary team competencies to result in coordinated and efficient team behaviour. Trained teams also exhibited significantly more teamwork behaviours as measured by the TARGETs approach.

A study by Stout et al (1999) aimed to examine how to develop shared mental models in teams via planning. In this study, the shared mental model was believed to provide team members with a common understanding of who is responsible for which task and what the information requirements are, such that team members can work together and anticipate the needs of others. Undergraduate participants performed a surveillance defence mission using a low-fidelity helicopter simulation. To assess the quality of team planning, trained observers rated planning across nine dimensions (creating an open environment; setting goals and awareness of consequences of errors; exchanging preferences and expectations; clarifying roles and information to be exchanged; clarifying sequencing and timing; unexpected events; how high workload affects performance; pre-prepared information; and self-correcting). The results suggested that teams (of four) that engaged in high-quality planning were able to form more developed shared mental models of each members informational requirements.

In attempts to find out more about shared mental models, Fowlkes et al. (2000) used an event-based knowledge elicitation technique that involved asking pilots (instructors and students) to view videotape of a helicopter flight (from initial briefing through the flight), completing questionnaires before each of four flight segments. Responses were then coded into one of three categories of shared mental model that were defined; declarative models consisted of concepts, facts, and rules associated with the missions (i.e., knowledge of roles and responsibilities, mission goals, etc); procedural models, which consist of knowledge associated with the sequence and timing of specific tasks (i.e., knowledge of crew member tasks, emergency procedures, aircraft position during mission, etc); and strategic models, which allow team members to apply both declarative and procedural knowledge for task specific situations. The responses from instructors predominantly concerned strategy and planning, whereas discussions of procedural aspects were more common for the students. While this approach was able to distinguish between instructors and students, it remains

unclear whether it would have the sensitivity to distinguish between teams of expert operators.

Kraiger and Wenzel (1997) suggested that the complexity of the shared mental model concept means that multiple measures are more likely to provide more valuable information. As stated earlier, research needs to give greater consideration to the measurement of team knowledge where the team is the unit of analysis.

4.2.1.2 Situational awareness

As is the case with shared mental models, the majority of research in the measurement of SA has been at the individual level. Major categories of measurement of SA include: subjective ratings, explicit performance measures, and implicit performance measures (Sarter & Woods, 1995). It is difficult to measure SA directly without it being contaminated by the actual decision making and performance tasks (Wickens et al., 1998). Adams et al. (1995) review measurement techniques in categories of on-line indices, indirect probes, and model-based approaches.

The most comprehensive review of measurement techniques was provided by Endsley (1995a). The various techniques reviewed for measuring SA include the following:

- Physiological techniques such as measurement of brain activity (such as the P300). This approach has been used as a measure of mental workload, but is unlikely to be of significant value in the measurement of SA as a state of knowledge. Heart rate and eye blink data have been used to measure SA in aviation (Vidulich, Stratton, Crabtree, & Wilson, 1994).
- Performance measures, which are usually objective and unobtrusive include:
  a) global measures of SA, which often suffer from lack of sensitivity. An overall measure of performance provides the output from a number of cognitive processes and is often masked by other factors; and
  b) external task measures typically involved removing aspects of the operator display and measuring the time it takes the operator to respond to that change.
- Subjective techniques (self-rating, observer rating).
- Questionnaires, which include the freeze technique, which involves stopping a simulation at random points in time and questioning the operator about their perceptions of the situation at that time.

An example of the freeze technique is the SAGAT which was developed to measure SA across all its elements based on a comprehensive assessment of operator SA (Endsley, 1987). It incorporates queries about SA across all three levels (in accordance with Endsley's (1995b) model), and considers system functioning and status and relevant features of the external environment. SAGAT is however only as good as the questions asked, and good questions require a task analysis and pilot testing to ensure the relevance of questions.

The SAGAT technique has been used as a basis for measuring SA in helicopter aircrew (Entin, 2000). A detailed measure of SA was developed that was based upon the SAGAT, and focussed on specific aspects of the situation. A second high-level measure assessed more general knowledge of the situation. Not only was Entin (2000) able to measure SA, but empirical support was provided for the hypothesis suggesting a relationship between SA and performance. The relationship between SA and performance is dependent upon the measures of both SA and performance that are used.

While most research into SA has focussed on measuring SA and designing better systems, there does appear to be a shift towards improving SA via training. For example, Endsley & Garland (2000) have made some recommendations for training SA in general aviation. Firstly, an SA error taxonomy was developed which identified types of SA errors (level 1-3) in accordance with Endsley's model. From this error taxonomy it was possible to identify the key problem areas for high SA in general aviation. Finally, it was possible to identify key areas where SA could be improved through training. For general aviation, these areas were: task management, development of comprehension, projection and planning (level 3 SA), and information seeking (seeking out the critical information) (Endsley & Garland, 2000).

Another approach is an event-based assessment of SA called SALIANT (SA Linked Indicators Adapted to Novel Tasks). It is based upon observed behaviours, and can be used to identify if an operator has difficulty with a specific task component related to SA. Since it is based on a list of behaviours, it can be used to standardise training in any number of situations. This approach has been used for pilot flight training (Fowlkes, Merket, & Oser, 2000; Milham, Barnett, & Oser, 2000; Sheehan & Oser, 2000). However, as is the case with shared mental models, there is a need for further investigation in the area of team SA.

4.3 Transfer of training

The focus of this chapter of the review to this point has been on how to assess the effectiveness of training on team performance by measuring performance during, or shortly after, a training exercise. The ultimate aim of most training programs is to enhance operator performance after completing the training program. The issue of transfer of training is whether the skills acquired during training transfer to relevant performance after training. It is worth noting here that excellent performance during training does not necessarily translate to excellent performance post-training.

Transfer of simulation training to subsequent real-world performance can be measured using the Transfer Effectiveness Ratio (TER) and the Training Cost Ratio (TCR). The TCR represents the time and/or cost of simulation-based training compared to real-world training. The most widely used measure of training effectiveness in the literature is the TER. A control group is required to measure a TER for training only on the actual equipment, however this is not possible for highly complex or non-operational systems (Holding, 1991).

Thorough and rigorous evaluation of training effectiveness and cost-benefit analysis requires the conduct of labour intensive transfer studies in which simulator training is conducted and performance on the simulator is compared with subsequent performance in the aircraft (e.g., Pfeiffer, Horey, & Butrimas, 1991; Taylor et al., 1999). In their simplest form, transfer studies involve comparing performance in the actual aircraft of a group of trainees who receive simulator training with a control group who receives training in the actual aircraft (Rolfe & Caro, 1982).

Transfer studies of this nature are very labour intensive and are therefore rarely conducted (Bell & Waag, 1998). In the aviation domain several transfer studies have been conducted to explore the impact of simulator fidelity on training effectiveness. This research challenges the belief that simulators of the highest visual fidelity offer the most effective training of procedural tasks (Johnson, 1981; Lintern, 1991; Lintern, Roscoe, & Sivier, 1990). For example, Lintern et al. (1997) found that transfer from simulator to actual aircraft was more effective for the low versus moderate scene detail of the flight simulation.

In addition to the impact of visual scene details, transfer studies have also examined the influences of other manipulations on training, such as pictorial versus symbolic displays, earth versus aircraft coordinates, display augmentation, and amount of simulator training (Lintern et al., 1990; Lintern et al., 1997; Pfeiffer et al., 1991).

The majority of aviation transfer studies are referred to as quasi-transfer studies, as defined by Lintern and colleagues. This refers to designs which examine transfer from several simulator training sessions to a test simulator configuration rather than a design that examines transfer from simulator to the actual aircraft. The advantage with quasi transfer is that training issues can be examined within a controlled laboratory environment. It is important to bear in mind that the results and principles from simulator training are only generalisable to the actual aircraft if one is able to demonstrate that the skills acquiring during simulator training are those that are required during actual flight (Lintern et al., 1990).

Transfer studies have also been conducted in domains other than aviation. One of the most labour intensive of all transfer studies comes from a five year program of research in the road safety domain. The final product was a CD-ROM based training product designed to accelerate the development of risk perception, attentional control, and time-sharing skills in learner car drivers (Regan, Triggs, & Wallace, 1999). Twenty-two simulator experiments were conducted in the development of the training product. These experiments investigated the perceptual and cognitive differences in driving skills between novice and experienced drivers, and techniques for training these skills (Triggs & Regan, 1998). The outputs of this research formed the basis for design specifications for the training product. Further details of processes involved in developing the package, and of the product itself, are published elsewhere (Regan, Triggs, & Godley, 2000; Triggs & Regan, 1998).

The training program was evaluated using a driving simulator with a total of 103 control and treatment participants. Participants attended six sessions over six weeks. Sessions 1 and 6 were pre and post-training simulator drives, and sessions 2 to 5 were the training drives for the treatment participants and control sessions using Microsoft Flight Simulator for the control participants. A final session 7 was conducted four weeks after session 6 (see Regan et al., 2000 for further details). The findings from this study suggest that the training program is effective in training both attentional control and risk perception skills and that these skills, once acquired, persist for at least 4 weeks after training. The product appears to be equally effective in preparing young novice drivers to safely handle risky traffic situations similar to those encountered during training (near skill transfer) as well as potentially hazardous situations that are new and novel (far skill transfer). This study highlights the intensive efforts required in the conduct of thorough transfer studies.

4.3.1 Summary

In summary, it is important to measure both individual and team performance, and both outcome and process measures of performance. Individual outcome measures determine whether the individual possesses the required competencies in order to effectively operate in the team, and individual process measures identify how individuals perform their tasks. Team outcome measures assess whether the team as a whole was successful in achieving its objectives, and the team process measures are required to determine how the team went about achieving its objectives (Cannon-Bowers & Salas, 1997a).

Measures of core dimensions of teamwork identify the degree to which teamwork behaviours are displayed by the team. These measures contain generic teamwork behaviours, in the case of the TOM, or identified behaviours that are specific to a given scenario in the case of the TARGETs approach. The measures of shared mental models and SA are very much aimed at the individual level and collated to represent team values, hence further effort should be directed towards exploring measures where the team is the unit of analysis.

With regard to transfer studies, there are many reasons for the low number of transfer of training studies in the literature. Some reasons are the same as for field-based training, that is, safety constraints dictate that simulation is the only means for training, for example, emergency procedures. Another reason is that some in the literature feel that there is a tenuous relationship between training and subsequent performance (Thurman & Dunlap, 1999). That is, training is only one factor that contributes to subsequent performance, and so it is difficult to isolate the influences of training only, and even if this could be done, performance measurement still remains a contentious issue (Thurman & Dunlap, 1999).

5. Conclusion

This review has been prepared as the first stage of Task Number AIR 01/248 Distributed Mission Training Systems for RAAF. The goal of this review was to review literature that would help to ensure the development of an effective distributed training system. While the RAAF DMT is initially aimed at skill maintenance in expert aircrew, wider literature relevant to the identification of processes that should form the focus of team training, theoretical perspectives on learning, techniques for training in complex environments, and the measurement of team processes, was reviewed.

With regard to the techniques for training in simulated environments, the EBAT approach to team training has been widely used in the military domain. This approach involves creating training scenarios that provide the trainees with opportunities to display the required teamwork behaviours. There may however also be a role for other forms of team training, such as team coordination training and cross training. The extent to which these other forms of team training might be involved in distributed training would depend largely on whether the teams were co-located or physically separated, and the extent to which it could be demonstrated that the critical team processes (SA, mental models, decision-making, etc) were addressed in the EBAT approach.

The literature concerning teamwork dimensions and processes is both interesting and inconclusive. There have been a number of cognitive processes for teams identified in the literature, and many more dimensions that are believed to be important for effective team functioning. The majority of studies use at least one of these teamwork dimensions in order to make inferences about team processes. For example, studies will often measure the dimension of communication in order to make inferences about the team's SA, or measure coordination to make inferences about shared mental models. The difficulty in interpreting the results from previous studies is that each study seems to use different combinations of teamwork dimensions to draw conclusions about team processes. There is some evidence for almost all of the identified team dimensions to be linked with improved team performance and training outcomes. While generic measures of teamwork such as the TOM seem to provide useful measures of teamwork, the more labor intensive and scenario-specific TARGETs approach provides more specific indicators of the degree of teamwork for a given team in a given situation. Very little seems to be understood about distributed team processes, and a better understanding of these processes is required to ensure more effective distributed training.

This review of the literature has highlighted several avenues for research that would benefit Task Number AIR 01/248 Distributed Mission Training Systems for RAAF.

Firstly, it is recommended that further research be conducted in order to ascertain the critical dimensions of teamwork for distributed teams, and as such, identify the more appropriate methods for collecting data relating to team processes in distributed teams.

This research would not be dependent upon having an available DMT system, but could be conducted using PC-based team performance software. It is important to enhance the understanding of the critical processes for distributed teams to facilitate the development of more effective DMT systems.

Secondly, it is possible that the EBAT will be considered for future RAAF DMT, and hence in the longer term is recommended that a distributed training exercise be conducted in order to gain valuable experience in creating and linking training objectives with both event-based scenarios and outcome measures of performance as well as measures of team process (such as TARGETs). There is in particular a further need to examine the efficacy of the TARGETs methodology for distributed teams.

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19. ABSTRACT

This report reviews literature relevant to team training in complex environments. While technological developments allow for the training of higher-order cognitive skills in complex simulated environments, in the absence of sound learning methodologies, training systems may not fully achieve their desired objectives. There are relatively few attempts in the literature that focus on how best to use technology to support effective training, and little research effort has involved the use of technology in the development of effective training programs for teams rather than individuals. The effectiveness of team training systems, and specifically, the measures of team outcomes and team processes that could be used to measure team performance in distributed training, are also reviewed. Some areas for future research relevant to distributed team training are identified.

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